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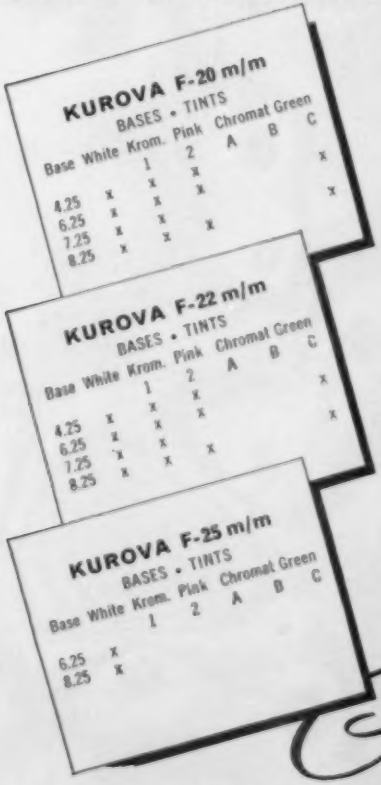

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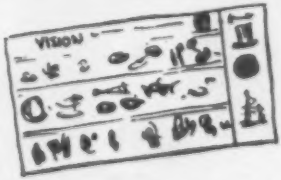

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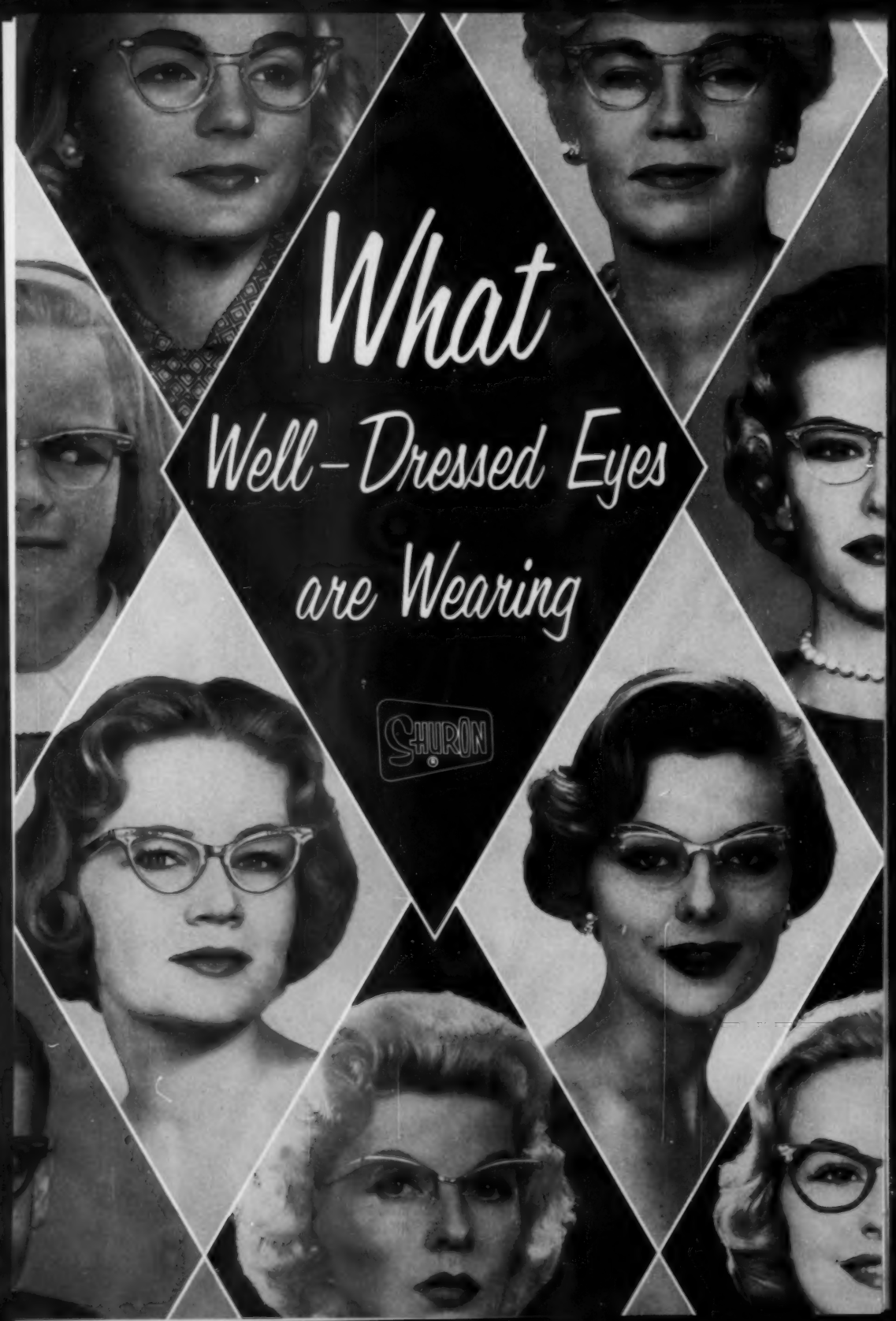
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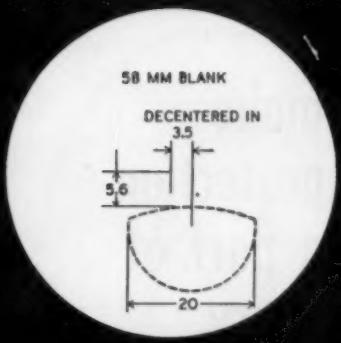

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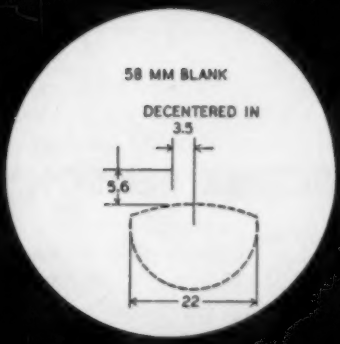

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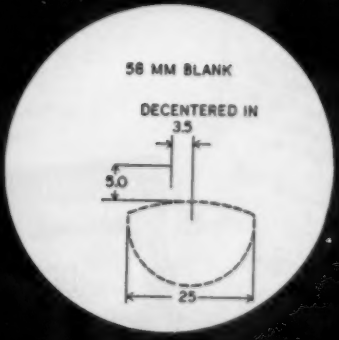

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GRAHAM'S THEORY OF COLOR BLINDNESS*

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INTRODUCTION

The term "red-green defects" embraces most of the hereditary types and subtypes of partial color blindness. The milder of these defects —the ordinary and extreme anomalous trichromasies—are really the largest physiological puzzles; but the two most severe red-green defects, protanopia and deuteranopia, have had the most attention from theorists just because they are the most severe.

Both the protanope and the deuteranope can match any light with some mixture of just two monochromatic primary lights. Needing only two primaries, they are called dichromates. Another kind of dichromasy is tritanopia, which is the least rare and most severe of the so-called "blue-yellow defects."

Under three-component color vision theory, any dichromate can be said to behave as if his system comprises only two components. The theory, as Helmholtz himself conceived it, offered three types of retinal receptors, each arousing an elementary color sensation embodying a pure hue and a moiety of the overall brightness. All of the hues seen, excepting the elementary three, were hybrids. The most unexpected of these latter was yellow, believed to be synthesized from the substrates of red and green. The redness receptors were believed to be absent in protanopes, the greenness visual cells were thought to be lacking in deuteranopes, and the third type of cone (responsible for blueness or for violetness) was supposed to be missing in tritanopes. Such losses removed one elementary and all hybrid hues from the chromatic repertoire of any given dichromate.

From the time protanopia and deuteranopia were first distinguished from one another (by Seebeck, in 1835), it was clear that the protanope sees the longer and longer wavelengths of the spectrum with progressively reduced brightness, and hence suffers a large slump of the effective photometric value of any "white" illumination containing all visible wavelengths. For him, the loss-of-a-receptor hypothesis orig-

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‡Sc.D., Member of faculty, Fellow, American Academy of Optometry.

inally seemed perfectly acceptable. But eventually the strange contentions of John Dalton and William Pole prevailed. They were scientists, themselves color blind, who analyzed their own cases in print. Although neither man had the least right to an opinion, both thought they knew which two of all the color-normal's hues *they* saw filling up the spectrum, and both thought that their only hues were yellow and blue.

One may or may not be sure that Dalton was a protanope and Pole a deteranope—it doesn't matter. Their writings convinced a majority that both protanopes and deuteranopes see yellow (and blue). Under the "loss" hypothesis of the simple three-component theory this would be impossible, which is one of the reasons why the Hering theory early made so many converts. But, the three-component theory was rescued in 1879 by Adelbert Fick.

Fick suggested that no type of receptor is entirely lacking in either protanopia or deuteranopia, but that in each condition the redness and greenness cones contain a single photopigment—in protanopia, the one appropriate to normal greenness cones, and in deuteranopia the one belonging to redness cones. The redness and greenness cones would respond equally to any stimulus, coupling redness and greenness, i.e., arousing a yellow sensory process *as if* yellow were a simple component. Both protanope and deuteranope would then see, in the spectrum, only yellow and blue, separated at the neutral point.

Fick's idea pleased three-component people excepting those who were bothered by the brightness aspects of the protanope's vision, which implied so strongly that a set of cones must be missing which, in the color-normal, contribute substantially to brightness. Everyone was finally satisfied by a compromise suggested without fanfare in 1935, and advocated more vigorously in 1944, by F. H. G. Pitt.

From his extensive studies of the color-matching and the brightness vision of protanopes and deuteranopes, Pitt was led to conclude that while Fick's explanation of deuteranopia was essentially correct, the protanope must indeed lack the redness receptors entirely, as Helmholtz had thought.

The situation did not remain satisfactory for very long. The late Selig Hecht, with his student Yun Hsia, re-investigated in 1947 the brightness vision of red-green dichromates and uncovered what he believed to be a paradox, the solution of which eluded him to his death.

If the amounts of energy required at various wavelengths to produce some standard high level of brightness are determined, and their reciprocals are plotted, points are obtained on a curve of the "luminosity" or "relative visual efficiency" of radiation. The ordinates

of the curve show how effective a unit of radiant energy or power is, for the production of sensory brightness, as compared with the efficacy of the most effective wavelength (where the ordinate is tallest, with its height called "1.000"). The curve is purely *relative*—there is no legitimate way to compare the curve of a dichromate with that of a color-normal. Raised to equal heights, the curves might have essentially equal areas; yet, for all one knew, the dichromate's *absolute* luminosities might be only half-normal at all wavelengths. Comparison of *relative* curves drawn equally tall begs the question of whether the dichromate has luminosity "losses," for one is then assuming what one is trying to find out: Does unit energy of white light give the dichromate the same brightness it gives the color-normal? Is the dichromate's brightness at his 100-percent-luminosity wavelength the same as the color-normal's brightness at *his* 100-percent-luminosity wavelength?

Hecht decided to treat, as if they were proper criteria of bright-light luminosities, the energies which would barely give cone sensations. He found these energies elevated in protanopes, so that the spectral curve of their reciprocals had only about half-normal area. This confirmed the idea that the protanope must lack a receptor important for brightness. But he found that similar data from deuteranopes indicated nearly as great a loss of white-light photometric value, as if the deuteranope also lacked a receptor—the greenness one, of course.

Hecht was thoroughly convinced of the fundamental correctness of three-component theory. He was just as thoroughly convinced that the only hues seen by both protanopes and deuteranopes are yellow and blue. He was not relying there upon the crystal-gazing of Dalton and Pole, but upon the established occurrence of individuals with normal color vision via one eye and red-green dichromatic vision by way of the other. All of the few such individuals had reported pure yellow and pure blue as their color-blind hues. All had had deuteranopic vision, but Hecht mistakenly believed that there had been at least one unilateral protanope among them.

The paradox, then, was that "luminosity" considerations showed that protanopes lacked redness receptors and should see no hues in the spectrum but elementary blue and elementary green, while deuteranopes lacked greenness receptors and should find no hues in the spectrum but componential blue and componential red—whereas the "fact" was that both kinds experienced yellow, and neither could have a sensation of either red or green.

Hsia never forgot the puzzle upon which Hecht had had to give up. Eventually he teamed up with Clarence Graham, and the two delved

into the problem, the real central question of which is the nature of deuteranopia. For the past four years they have been exploring and exploiting the visual functions of a young woman, "A.H.C.," who has one normal and one deuteranoid eye. This program has ended, since the removal of A.H.C. from New York to Los Angeles. The first of a series of papers, based largely upon her case, has appeared (Graham and Hsia, 1958).

Although Graham and Hsia will be having much more to say eventually, this first paper already sets forth the body of a new theory, completely enough so that one can see what the evidence for it is, how good that evidence is, and what to think of the theory.

Graham's theory explains both deuteranopia and protanopia upon largely common ground, so that the two things are accounted for that seemed incompatible to Hecht: the perception of both yellow and blue by both kinds of dichromates: and the losses, in both, of so much luminosity as to imply the absence of all of the receptors of some one of the three types. The theory is clever indeed, and yet is so simple that one may well believe that Hecht would have thought of it himself, if only he had lived a little longer.

The theory neatly blends the main idea of Fick (two receptor populations containing the same photopigment instead of two different ones) with the main idea of Young and Helmholtz (important brightness-generating receptors reduced in numbers, pulling down the ratio of sensory brightness to stimulus energy). For the protanope, it says that the numbers of *both* the redness cones and greenness cones are reduced (but only by about half—not to zero in either case). This accounts for the depression of the absolute luminosity curve. The shape of the curve, and the protanope's reputed enjoyment of a yellow sensation, are brought about by having the residual redness cones contain the greenness cone's photopigment. For the deuteranope, the theory claims a similar equal (but lesser) reduction of the numbers of both redness cones and greenness cones, mediating a large reduction of absolute luminosities along the spectrum: and, the presence of the greenness cone's photopigment in the remaining redness cones and greenness cones both. Thus the deuteranope will also have redness and greenness inextricably coupled in yellowness, yet a sizable slump of brightness particularly through the middle of the spectrum. If the facts Hecht could not fit together are indeed facts, then in Graham's theory they do dovetail beautifully.

In considerable preliminary work, Graham and Hsia determined spectral threshold energies at the fovea for five protanopes, six deuteranopes, and seven normals. This was essentially repetition and exten-

sion of the old work of Hecht and Hsia, but with much better technique. Plotting the reciprocals of the thresholds (standing for sensitivities) along the spectrum gave them "luminosity curves," so that wherever the dichromate curves fell below the normal curve they could claim "luminosity loss." The extent of the losses is obscured by their logarithmic expression (in their Figure 2). Between $\lambda 450 m\mu$ and $\lambda 680 m\mu$ I make the integrated white-light luminosity loss to be 24.3 percent for the deuteranopic group. It would have been larger but for the fact that one of their six deuteranopes showed no "losses" at all. At any rate, although the figure is much smaller than the 38.8-percent deuteranopic luminosity loss determined in the work of Hecht and Hsia, it is large enough to be bothersome to the straight Fickian explanation of deuteranopia. Immediately, however, so small a loss for deuteranopes as 24.3 percent would forbid any explanation of deuteranopia by a simple loss of all greenness receptors. The supernumerary blueness receptors taking their places would have to produce a larger share of brightness than that for which anyone would care to make them responsible.

Only some of the work on A.H.C. is covered in the recent SCIENCE paper, which is based upon an oral address delivered by Graham in December, 1956. Most of the rest has already been "pre-published" elsewhere however, via disseminated copies of later oral presentations by Graham, in symposia both in this country and abroad.

There seems no doubt that A.H.C.'s right eye is color normal, if indeed it is not supernormal (in overall wavelength discrimination). There is no doubt that with her left eye she is dichromatic, with a neutral point at $\lambda 501 m\mu$ (matching 5000°K white), and capable of matching any wavelength with mixtures of only the two primaries $\lambda 460 m\mu$ and $\lambda 650 m\mu$. The only hues in its subjective spectrum are a pure blue shortwaveward, and a pure yellow longwaveward, from the neutral point. These are matched by the hues of $\lambda 470 m\mu$ and $\lambda 570 m\mu$ as seen by the normal eye.

If we call "regular" the deuteranopia of the typical individual who has two deuteranopic eyes, then in spite of the above statements A.H.C.'s defect is not regular deuteranopia. Graham and Hsia say that she "did not give completely typical deuteranopic responses, particularly in hue discrimination. However, it seems clear that she is more nearly classifiable as a deuteranope than as any other type of color-blind individual, and we believe that her results have a particular bearing on deuteranopia."

Graham and Hsia established a depression of brightness vision for A.H.C.'s left eye, in three different ways. For each eye, they determined the same sort of foveal spectral "luminosity" curves, from threshold

data, as with their regular deuteranopes. From the violet to about $\lambda 630 m\mu$, the left eye showed even larger "luminosity losses" as compared with the right eye, than the regular deuteranopes showed as compared with color normals.

In a second method, it was assumed that the critical fusion frequency for a light is a proper criterion of the subjective brightness of that light. Critical fusion frequency data taken at various luminances at three spectral loci indicated that at $\lambda 452 m\mu$, brightness was somewhat lower for the left eye than for the right, that at $\lambda 539 m\mu$ it was very much lower, and that at $\lambda 640 m\mu$ there was no difference.

Finally, A.H.C. was trained to make direct binocular matches of brightness in a split field, half of which was seen by each eye. When each monochromatic light was put into both halves, it could be directly determined by what factor the luminance had to be raised for the left eye, to obtain brightness equality with the right. This work seems to have been done too recently to be included in the SCIENCE article ("frozen" in December, 1956). The results were not less than fascinating.

At particular wavelengths, the luminance-multiplying factors for the left eye went as high as *ten* (relating to a luminosity loss of 90 percent). My own plotting of the left eye's losses downward from a normal luminosity curve yields a luminosity curve for A.H.C.'s left eye which peaks in the neighborhood of $\lambda 590 m\mu$ and looks essentially like the spectral responsivity curve of a redness receptor uniformly lowered. A curve drawn through a plot of the losses themselves peaks at about $\lambda 540 m\mu$, making it strikingly reminiscent of the responsivity curve of a greenness receptor.

This may make it appear that for A.H.C.'s left eye the luminosity losses are due simply to the removal of all greenness receptors (leaving her perception of yellow inexplicable). But one must consider the surprising extent of the losses. My trial-balloon curves, cut out and weighed on an analytical balance, show that A.H.C.'s left eye loses 73 percent of the photometric effectiveness of a white light. Although the losses appear to be caused by the greenness receptor, it is not through its simple absence (which would not remove so much brightness). Rather, it would seem that photochemically normal greenness receptors must be present, and exerting inhibition upon brightness in proportion to their own activation. This would mean that in A.H.C. the coupling of redness and greenness into yellowness must be neural rather than caused by a photochemical identicalization of receptors. There is no obstacle in the way of that.

In Graham and Hsia's SCIENCE article, Figure 8 fully expresses

the theory which is based so largely upon the situation in A.H.C. (See illustration.) The graphs there are intelligible, however, only with knowledge of what Graham has said about his theory elsewhere, and then only if one ignores the unfortunate calibration of their ordinate scales.

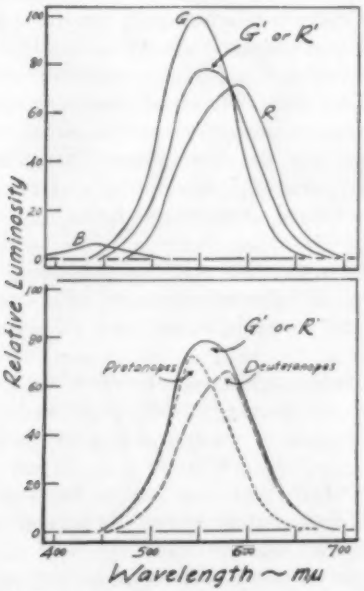

Figure 8 reproduced from Graham and Hsia, SCIENCE, 1958.

In the upper graph, a normal luminosity curve would be obtained by summating the receptor curves G and *R*. Let the photochemical contents of both the greenness and redness cones now be changed to give both receptors an absorption spectrum shaped like "G′ or *R*′," and redness and greenness will be permanently coupled in yellowness. The "G′ or *R*′" curve then represents two curves, G′ *and* R′, superimposed Doubling its ordinates adds them together and yields a *normal* luminosity curve, so that this upper graph represents an imaginary dichromate whose hues would be yellow and blue but whose luminosity curve would be normal and whose neutral point would be neither protanopic nor deuteranopic.

The lower graph depicts what Graham hypothesizes to be "reality." The curve marked "*Protanopes*" is a greenness-receptor curve representing the absorption spectrum of a normal greenness cone and an

abnormal redness cone, superimposed, with both pulled down in height to represent the loss of some cones of both kinds. Redness and greenness are always equally aroused and hence coupled into yellowness, and doubling the height of the *"Protanopes"* curve will give a protanopic absolute luminosity curve with only about half-normal area under it. The *"Deuteranopes"* curve similarly stands simultaneously for chemically identical redness and (abnormal) greenness cones, with numbers reduced and reduced equally. Doubling its ordinates will give a deuteranopic luminosity curve with subnormal area, explaining the "luminosity losses" the deuteranope is supposed to suffer excepting in the red region. The identity of the superimposed curves marked *"Deuteranopes"* explains, of course, the deuteranope's seeing of yellow and inability to experience redness or greenness alone.

CRITICISM

This theory rests upon three main suppositions:

(1) Protanopes, like deuteranopes, see yellow and blue in the spectrum and therefore cannot lack all the receptors of any one type.

(2) Regular deuteranopes, like protanopes, have considerable depression of photopic luminosity and brightness, but especially marked in the blue and green regions rather than in the red.

(3) In those visual functions which bear upon the theory, A.H.C.'s defect is close enough to regular deuteranopia for her to constitute valid evidence.

The first of these suppositions is based entirely upon the identification (in 1880) of a single unilateral color-blind, named Hermann Goldenberg, as a protanope. He was vigorously denied to be a protanope by von Hippel, who studied him exhaustively in two different periods. Between times, he was pronounced a "red-blind" (protanope) by Holmgren, solely upon the basis of the Wool Test. The only writer on unilateral color blindness referred to by Hecht and Hsia (von Kries) thought long afterward (1919) that it was probable but not certain that Goldenberg was a protanope. He was called a deuteranope by contemporary experts greater than Holmgren—Arthur König among them. It is perfectly easy to see from von Hippel's first-hand descriptions that Goldenberg was indeed deuteranopic. He had a normal relative luminosity curve and a neutral point at $\lambda 512 m\mu$. This whole matter was fully treated by Walls and Mathews (1952). The fact that Goldenberg's only hues were yellow and blue serves to confirm his deuteranopia, rather than to prove that a protanope loses brightness through lacking

only half of his red cones but half of his green cones as well, with the remainder of both containing green-cone photopigment.

The second supposition rests upon the *small* elevations of foveal cone thresholds found by Graham and Hsia for shortwave and mid-spectral lights, in five out of six regular deuteranopes. The investigators at least courageously reject the much more attractive (to them) values of Hecht and Hsia. But in the first place, elevation of threshold nowise implies reduction of *photopic* luminosity, for in any type of color blindness the slope of the approximately straight line relating cone brightness to log intensity (Fechner's Law or Plateau's Law, as one pleases) may be anything. What it is, has to be established and cannot be assumed.

Graham has resurrected some old data showing depressed photopic critical flicker frequencies for deuteranopes, to bolster his assumption that regular deuteranopes suffer genuinely photopic luminosity loss. The *newest* of the investigations in question was done years before the invention of the anomaloscope, and it is not at all certain that the investigators knew a deuteranope from Paddy's pig.

Gordon Heath investigated photopic critical frequencies in deuteranopes as compared with protanopes and normals, as a doctorate-thesis research designed to elucidate Hecht's paradox. This large work has not yet been published, but I have seen a preliminary paper which is in preparation, and can say that Heath's six guaranteed deuteranopes (by the flicker criterion which Graham himself validated for A.H.C.) showed no losses anywhere, but *gains* of photopic luminosity at all wavelengths longer than 520 mμ. The integrated (white-light) luminosity for Heath's five protanopes was only 64.7 percent of that for his nine normal controls: but the area under his deuteranopes' curve was 136.2 percent of normal. Unless it be claimed that critical flicker fusion frequencies are not related to brightness, this should dispose of the supposition that there is any photopic light that looks less bright to a regular deuteranope than it does to a color-normal alongside.

We come now to A.H.C. The reductions of luminosity for her left eye were so large and so easy to quantify that she may have made it seem unnecessary to supplement the threshold intensity measurements on regular deuteranopes with photopic flicker measurements. Graham and Hsia, not looking for and finding what Heath did, have made the assumed "regularity" of A.H.C.'s luminosity data carry almost the whole load of their inclusive explanation of deuteranopia and protanopia. But Heath's findings prove that the "deuteranopia" of A.H.C.'s left eye is *not* regular. Its luminosity depression is greater even than that in a protanope, whereas regular deuteranopes enjoy supernormal bright-

ness. A.H.C. is not even like other unilateral deuteranoids. Sloan and Wollach (1948) described a male unilateral whose deuteranopia was indisputable. For him, $\lambda 452 m\mu$ had the same hue, saturation, and brightness for either eye, whereas for A.H.C.'s left eye the luminance at $\lambda 452 m\mu$ had to be raised 589 percent to make it as bright as for the right. Sloan and Wollach's subject saw $\lambda 584 m\mu$ *brighter* with his deuteranopic eye than with the other. For A.H.C.'s left eye, luminosity at $\lambda 584 m\mu$ is only about 35 percent of normal.

Further evidence of A.H.C.'s difference from regular deuteranopes is seen in her "hue discrimination curves," given in Graham and Hsia's Figure 6. For such a curve one determines, at many places in the spectrum, the difference of wavelength ($\Delta\lambda$) which at constant brightness affords a bare difference of color. The values of $\Delta\lambda$ are then plotted against λ (wavelength) itself. The curve is mis-named—it is a *wavelength*-discrimination curve and nothing else, for saturation is a variable along an equal-brightness spectrum, as well as hue.

When the normal curve is obtained in an instrumental field of the usual size, it exhibits two prominent minima, in the blue-green and in the yellow, where $\Delta\lambda$ is as small as 1 $m\mu$. Smaller values are obtained throughout, in a field of 10° diameter or so—but the two minima are always still there. The curve for A.H.C.'s normal right eye, curiously, does not show them. It is almost flat at a height of a little over 2 $m\mu$, rising gently from the orange to the far red, and again in the far violet. Graham and Hsia nevertheless call this curve "not . . . greatly different from the usual . . ."

Their characterization of the left eye's curve is even more surprising: "The behavior of hue discrimination in the spectral region from 500 to 750 $m\mu$ is similar to that found in the usual deuteranope." There may be a misprint here, for the curve in their Figure 6 does not go to 750 $m\mu$ but stops short of 675 $m\mu$. Between $\lambda 500 m\mu$ and its red end the curve exhibits three rises and two dips. The whole curve for a regular deuteranope, on the other hand, is shaped like a simple narrow parabola centered upon the wavelength of the neutral point, with $\Delta\lambda$ rapidly reaching infinity at either side thereof (Pitt, 1935), and short of $\lambda 530 m\mu$ on the longwave side. One expression of this is the familiar fact that at the Nagel anomaloscope a regular deuteranope can match the monochromatic yellow against the monochromatic green or the monochromatic red, or any mixture of the two. How A.H.C. may behave at the Nagel anomalscope, I do not find Graham saying anywhere. While she sees only one particular yellow hue longwaveward from her neutral point, I do not doubt that the saturation of it goes up and down repeatedly from $\lambda 500 m\mu$ to $\lambda 650 m\mu$. The absence of

the 530mμ-650mμ plateau of saturation is not incompatible with the neutral point, a two-hue spectrum, and colorimetric dichromasy. But it helps to make it impossible to consider A.H.C. a practically regular deuteranope.

The reason for A.H.C.'s irregularity, if not a physiological explanation of it, is seen in the genetic status of her defect. This is a matter upon which so far Graham has apparently said nothing in any presentation of the work on A.H.C. and the theory inspired by it. Independently, however, both Graham and Hsia have told me the situation in correspondence.

Herself trained in psychology, A.H.C. has given several color-blindness tests to all available relatives without finding any to be defective. Her parents have been examined by Graham and Hsia, with five tests. Her mother and a brother are perfectly color-normal. So is her father on all tests he has been given (most of them, pseudoisochromatic), with the sole exception that he sets a homemade filter anomaloscope a bit redward and *could* be called very slightly protanomalous ("by definition") for this one reason.

If her father had a deuteranopia gene it would have made him a deuteranope, and A.H.C. could not have escaped receiving it. Since he cannot have given her one, she cannot have more than one gene for any deuteranoid defect. This is presumably (though not certainly!) a gene for deuteranopia, which her mother "carries" and could give to A.H.C. although, like nearly all women with only one gene for deuteranopia, she herself shows no sign of it. So, A.H.C. is one of those rarities, a woman heterozygous for deuteranopia who is color blind whereas "theoretically" she should be color normal, like her own mother.

Considering this, it is no surprise that A.H.C.'s "deuteranopia" is so irregular, luminosity-wise and with respect to intrinsic spectral saturations. It is not that there is any reason to attribute her unilaterality to her heterozygosity—unilateral red-green defectives are at least as often male as female, and a male could not be a heterozygote for a sex-linked trait. But, it does have to be said that no known binocularly red-green-color-blind heterozygote, carefully studied, has yet been shown to have the *regular* version of a color defect for which she has only one gene.

A heterozygote for protanopia may have "protanopia" with irregular luminosity, a heterozygote for deuteranopia may have "deuteranopia" with an irregular RDP situation and an irregular neutral-point position, and there is even one known compound heterozygote for protanomaly and deuteranomaly who "should" be normal but is totally

color blind (see Walls, 1955). A weird luminosity curve is most likely to be found in an individual known or suspected to be heterozygous for some color-blindness gene which ordinarily affects that individual's sex only when in duplicate. Luminosity "losses" are scattered through the literature, and luminosity "gains" as high as 60 percent have been reported (Fischer *et al.*, 1951).

If there is no evidence that protanopes have yellow sensations, if regular deuteranopes have not subnormal photopic brightness, but supernormal, and if A.H.C.'s "deuteranopia" is no such thing but rather is one of those unique defects which we are coming to expect only in heterozygotes such as she, then Graham's theory of the nature of deuteranopia and protanopia remains ingenious and interesting—but seems unnecessary. Pitt's analysis retains the most appeal, for one who wants to defend the three-component theory against those who say that "it won't explain the similarities and differences of protanopia and deuteranopia."

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A NEW ASTIGMATIC TEST CHART*

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The need for a sensitive method for the detection of the degree and angle of astigmatism has been demonstrated by the many astigmatic charts and tests which have been devised during the past fifty years.[1, 2] Some of the charts have been sensitive but too complicated for easy use and others have been relatively insensitive. A simple chart may be sufficiently sensitive and provide the necessary information for most practical purposes. On the other hand, a more complex chart may be needed for a more critical evaluation of astigmatism, especially for those researches in which a precise knowledge of astigmatic errors is desired.

Typical of such researches are those dealing with the orientation of test objects. Several investigators[3-10] have studied the "preference for vertical and horizontal" by the determination of visual acuity with variously oriented test-objects. The investigators usually have stated that the astigmatism of each observer had been "fully corrected."

Recently, while obtaining visual acuity measurements with parallel-bar test objects at different orientations the *apparent* preference for the vertical and horizontal over the oblique was confirmed. Since all of the observers wore their normal correction, if any, it was assumed that their astigmatism was adequately corrected. However, during the experiment suspicions arose that a small amount of uncorrected astigmatism might have been responsible for the orientation preference. This led to a search for a more suitable target for use in orientation experiments.

DESIGN OF TEST OBJECT

In order to select the most suitable test object for studies of preference for certain orientations of targets, many existing patterns were examined and new ones were developed. Among these targets, one was found to be superior to the others. Preliminary investigations indicated that certain characteristics of the pattern made it sufficiently sensitive to reveal the existence of small amounts of uncorrected astigmatism.

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Four bar-type test objects which are representative of those investigated are shown in Figure 1. Some brief comments on each may be pertinent.

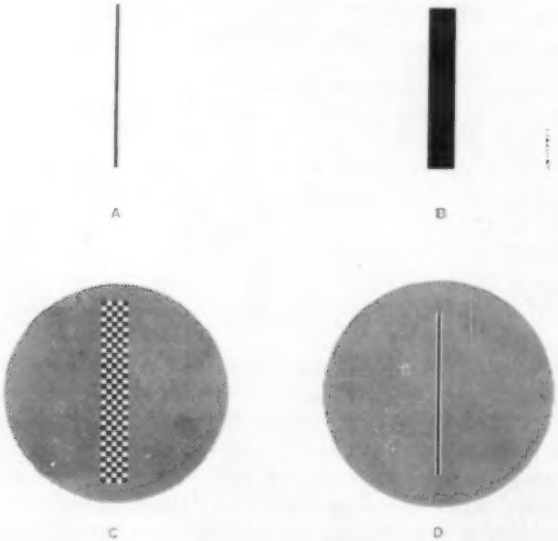

Fig. 1. Illustrating four test objects representative of those investigated.

A. A thin line would be expected to be sensitive to orientation because the width can be selected to be close to the acuity threshold. However, the degree of blur is such that small amounts of astigmatism may not be detected. This is equivalent to one of the lines of the conventional astigmatic dial chart.

B. A wide bar would be expected to be relatively insensitive to orientation because the width is well above the critical size for acuity measurements.

C. A checkerboard bar was suggested by the Goldman checkerboard visual acuity chart.[11] The checkerboard of the bar can be seen against its background of the smaller squares only when its larger squares are above the acuity threshold. While acuity is involved in detecting the bar, its overall size is such as to be relatively unaffected by astigmatism. However, when the checkerboard bar is viewed near threshold conditions, it appears to be made up of diagonal black and white stripes. Thus, internal orientations produce a pattern that competes with the orientation of the bar itself. Its theoretical effectiveness as an orientation target thus becomes questionable.

D. This type of design of alternate black and white bars was developed as a result of investigations of various arrangements of squares and stripes.

The final design, illustrated in Figure 1D, consists of a background area of equal black and white lines upon which is superimposed a wider black line. The white space immediately surrounding the center black line has been adjusted so that the black and white areas of the entire disk are equal. When all the details of the test object are below the threshold, the entire disk appears uniformly gray with an apparent average reflectance of 50 per cent. Under this condition the center target line blends into the background.

As the disk is viewed progressively from suprathreshold to subthreshold conditions by, for example, decreasing the illumination or increasing the viewing distance, the transition of the target line from visibility to invisibility occurs relatively sharply. On the other hand, when the same width target line is viewed against a white background (Figure 1A) it merely appears to become blurred and the threshold is much less definite. This desirable feature of a more precise threshold suggested that such a design would be of considerable value as an orientation target and also could serve as a basis for a sensitive astigmatic test chart.

An analysis of why the target line on the ruled background becomes invisible while a similar target line on a white background remains visible is presented schematically in Figure 2. Portions of the two types of targets are shown in the upper part of the diagram (*a* and *d*). The middle and lower sections of Figure 2 illustrate the relative brightness distributions[12] on the retina for two viewing conditions.

Figures 2b and 2e represent the retinal brightness patterns when, for example, the viewing distance is such as to make the background pattern of the new test object subthreshold. The narrow black and white lines of the background (Figure 2d) produce sufficiently blurred images (Figure 2e) so that they blend together and appear as a uniform gray area.[13] However, since the white border around the target line is wider than the white lines of the background, the degree of blur is insufficient to reduce the target to threshold of visibility. The target line on a white background is highly visible as indicated by the retinal brightness pattern of Figure 2b.

When the test objects are further reduced in visibility the single line target (Figure 2c) appears slightly blurred but still is easily seen. The target bar of the new test object (Figure 2f) blends into the background and becomes invisible. Direct comparison in the laboratory has

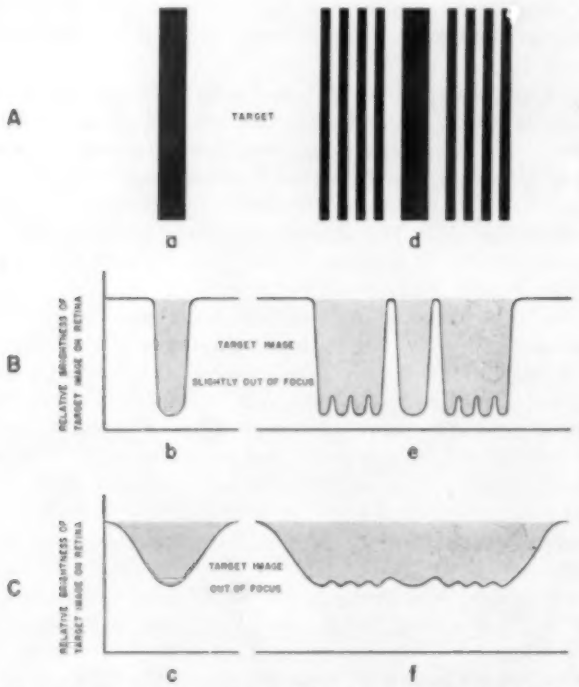

Fig. 2. Schematic representation of retinal brightness distribution obtained with a black line on (a) white background and (d) new ruled background.

indicated that the rate of change of visibility with changes in illumination or viewing distance is more rapid for the new target (Figure 2d) than for the single line on a white background (Figure 2a).

COMPARATIVE TEST

The results of a comparative test of the four targets shown in Figure 1 are presented in Figure 3. The threshold brightnesses of the white areas of the targets were determined for 4 orientations (vertical, horizontal, diagonally right and diagonally left) for each of the targets. Brightness changes were obtained by observing the target through a Luckiesh-Moss Visibility Meter in which the variable density filters having diffusing qualities had been replaced by a non-diffusing type. Since no diffusion was present, changing the density of the filters produced corresponding changes in the brightness of the test objects. Observations were made monocularly with the right eye by a subject wearing a prescription which gave about 20/20 vision with an apparently satisfactory correction of astigmatism.

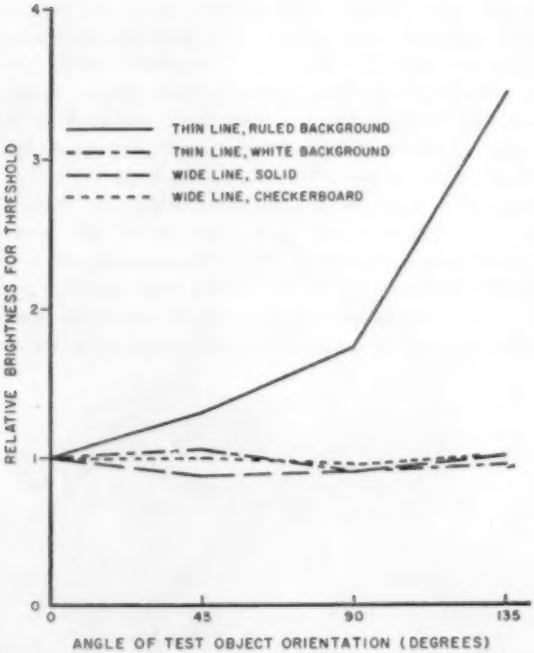

Fig. 3. Comparison of threshold brightnesses for the 4 test objects shown in Fig. 1 for several orientations of the line targets.

The threshold brightnesses shown in Figure 3 show no significant difference for test objects A, B and C. On the other hand, with the new test object D, a ratio of 3.5/1 was obtained between the threshold brightnesses for the meridians of minimum and maximum visibility. In other words, astigmatism was not completely corrected. A further check indicated that the remaining uncorrected astigmatism corresponded to slightly less than 0.25 diopter.

An additional exploratory experiment was conducted by Brecher and Lewis[14] using test objects based upon the designs shown in Figures 1A and 1D. Eleven subjects, under cycloplegic, made comparative subjective tests.

For each subject, the target line with the ruled background was oriented at the meridian of maximal visibility. The test object was viewed monocularly through an optical device which permitted the subject to make continuously variable adjustments of cyclindrical dioptric power in any desired meridian. After the target line was blurred

with plus power until it was indistinguishable from the background, the subject was required to determine (1) the least plus power which made it just barely visible and then (2) the necessary plus power which made it just blend with its background. Similar responses of "just appeared" and "just disappeared" were made by varying the minus power of the lens system. Thus, the dioptric range in which the test line was clearly visible to the observer was determined.

The same procedure was used for the single line object with the exception that the judgments of "just clear" and "just blurred" were used rather than "just appeared" and "just disappeared."

The results obtained by Brecher and Lewis are shown diagramatically in Figure 4. For each type of test object the clear portion represents the range of dioptric power for clear visibility of the target line.

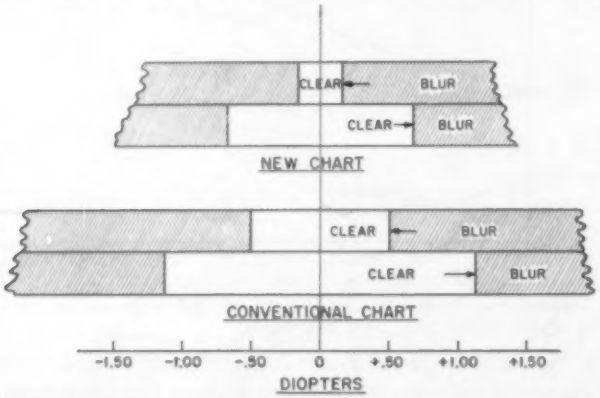

Fig. 4. Illustrating the threshold ranges in diopters obtained with the new astigmatic test chart and a conventional astigmatic chart.

The upper bar for each chart shows the range as obtained with measurements being made from blur to clear and the lower bar for each chart is the range as obtained with adjustments being made from clear to blur. The arrows indicate the direction of adjustment of the plus power lens system. Similar adjustments were made in the minus power lens system.

For the new chart the region of clear vision as determined by the "just appeared" threshold was 0.3 diopter and for the conventional chart it was 1.0 diopter as determined by the "just clear" threshold. For the "just disappeared" threshold the new chart had a range of 1.3 diopters and the conventional chart had a range of 2.3 diopters for the "just blurred" threshold. The narrower ranges of dioptric power for

clear visibility for the new chart as compared with the conventional chart indicate that the new chart is the more sensitive of the two.

ASTIGMATIC TEST CHART

The astigmatic test chart which was developed as a result of this investigation is shown in Figure 5. It corresponds to a combination of four orientations of the basic test object shown in Figure 1D. The widths of the background lines were selected so that they would be below threshold at a viewing distance of 20 feet. The target lines were designed to be above threshold at this distance. The target lines in this new chart are three times the width of the background lines. The latter were made discontinuous at the center in order to eliminate a large black area at their intersections. The small center design maintains the equality of black and white areas.

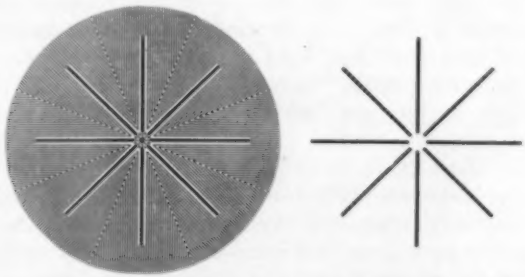

Fig. 5. Illustrating the new astigmatic test chart. For purposes of comparison a conventional sunburst chart also is shown.

The basic idea of a target blending into a gray background is not new. In 1924 Friendenwald[15] constructed a radial line chart with the lines surrounded by a white border against a background of uniform gray. The arrow test chart developed by Raubitschek[16] also uses a gray background. A principal problem of a solid gray background is the difficulty of obtaining printed reproductions without mottling. One advantage of the new chart is its easy reproducibility.

Although the new chart was developed for a test distance of 20 feet, sufficient data have not been obtained to determine whether or not it is of ideal size. If the chart is too large it will not be effective and if it is too small it cannot be seen as clearly as necessary.

Level of illumination also is important when using the chart. Since acuity increases with illumination, it may be possible that a sensitive astigmatic target such as the one described in this paper might also be sensitive to changes in illumination. Brief checks have indicated this to

be the case. This points the way to further experimentation to show the effects of illumination on astigmatism.

The new chart also provides a tool for further study of the relationship between astigmatism and the orientation of targets. There is some indication that it may not be possible to actually fully correct astigmatism by presently employed methods, and that the uncorrectable astigmatism may be the cause of the so-called preference for vertical or horizontal over the diagonal. Further study in this area is needed.

SUMMARY

A new astigmatic test chart has been designed using the conventional sunburst of lines, but with the lines surrounded by a ruling of narrower lines which blur into a uniform gray background at the proper viewing distance. When the radial target lines are blurred by astigmatism, they fade into the background and disappear rather than merely becoming blurred as with the conventional chart. Less astigmatic error is required to blur the target lines to invisibility. Furthermore, the design appears to make smaller degrees of blur more obvious to observers. The new chart is thus more sensitive in the detection of astigmatic errors.

The new chart should be an effective tool for the subjective testing of eyes for astigmatism. Whether it is suitable for normal use will depend upon clinical experience. Present techniques and charts appear to be adequate in most cases. For some individuals, however, astigmatic errors seem to be extremely critical and a need for a sensitive chart of this new type may be indicated.

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ANNOUNCEMENT

PENNSYLVANIA STATE COLLEGE OF OPTOMETRY

The Pennsylvania State College of Optometry announces the offering of a post graduate course in the fitting of contact lenses from November 16 to 22, 1958.

It will consist of 28 hours of clinical practice, actually fitting patients, under the instruction of Dr. John C. Neill, director of the college's contact lens clinic, and 21 hours of lecture work. Doctor Neill will lecture seven hours on the prescribing, evaluating and fitting of contact lenses.

Dr. F. W. Sinn, professor of physical and geometrical optics, will lecture six hours on the optics of contact lenses.

O. G. Rybachok, professor of anatomy, will lecture four hours on the anatomy of the anterior segment of the eye.

Dr. Harold Simmerman, professor of ocular pathology, will lecture four hours on pathology related to contact lenses.

The class will be limited to 12 students. The fee is $100, which is required in advance to reserve a place in the class. Further information and application form may be obtained by writing: Dean, Pennsylvania State College of Optometry, 6100 North 12 St., Philadelphia 41, Pa.

AN EVALUATION OF THE MASSACHUSETTS VISION SCREENING TEST AND ITS IMPLICATION ON THE GENETIC THEORY OF MYOPIA*

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INTRODUCTION

The most effective system commercially available for the visual screening of school children, according to Ryan,[16] Robinson[15] and Leverett[11] is the Massachusetts Vision Test. These authors base this preference on the low over-referral rate, speed of application and simplicity of administration.

The present investigation utilized the American Optical Company model 11300 to screen 1,909 children. The test was administered to 1,079 children of Air Force personnel in the Loring Air Force Base school and to 830 children in the school system of the neighboring community of Limestone, Maine.

In order to permit comparison with previous studies, the examination technique and standards of performance suggested in the manual accompanying the test were followed.[12] A child was failed if he did not meet the standards on one or more of the following subtests:

1. Visual acuity for either eye was less than 20/20.
2. Acuity through plus 1.50 diopter lens for grade 3 and above, or plus 1.75 diopter for grades 2 and below was 20/20 with either eye, or 20/30 with both eyes.
3. Vertical phoria or tropia at twenty feet was greater than 1.25 prism diopters.
4. Lateral phoria or tropia is greater than 6.0 prism diopters "eso" or 4.0 prism diopters "exo" at twenty feet.
5. Lateral phoria or tropia greater than 6.0 prism diopters "eso" or 8.0 prism diopters "exo" at sixteen inches.
6. Evidence of a tropia on the monocular cover test.

Subtest 6 is not part of the regular battery, and was added to evaluate the number of tropias not detected by the preceding five subtests.

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In keeping with the suggestion reported by Krajcik,[10] volunteers from the PTA groups were given an intensive course of instruction in the theory and administration of the test. It is noteworthy that the PTA of the Base school financed the purchase of the instrument and permitted the town of Limestone to make use of it for screening the non-military children.

In accordance with the suggestions of Ryan, Leverett and the American Optical Company manual (written by Leverett and Backer), no referral was made unless the child failed both the first test and a retest. On the initial test, failure on any item was sufficient to result in failure of the entire test, whereas on the retest, every item was administered in all cases. Children wearing spectacles were tested with these in place.

As an aid to the evaluation of results as well as to provide specific information to the doctor consulted, a form listing the items failed, together with an explanatory note was sent to the parents. The doctor was requested to return the form with a short note reflecting the validity of referral. Contrary to Leverett's procedure, the same referral was made for children with or without spectacles. A failure was evidence that the child's vision as he normally attended school, Hofstetter's "working vision,"[7] was less than standard.

COMPARISON OF RESULTS BETWEEN BASE AND LIMESTONE CHILDREN

Table I presents a summary of the results for the Base and Limestone children. Inspection of the data reveals two striking differences between the groups. Apparently, more Limestone children wear spectacles and more Limestone children failed the test than did Base children.

TABLE I.
Summary of results of screening Base and Limestone Children.

Grade	Total	Wear Spectacles	Fail Retest	Fail with Spectacles
BASE CHILDREN				
Sub Pr	95	0	34	0
1-8	984	111 (10.3%)	301 (30.6%)	50 (45.1%)
Total	1079	111 (10.3%)	335 (31.1%)	50 (45.1%)
LIMESTONE CHILDREN				
1-8	563	97 (17.2%)	204 (36.3%)	56 (57.8%)
9-12	267	89 (33.3%)	109 (40.8%)	56 (63.0%)
Total	830	186 (22.4%)	313 (37.7%)	112 (60.3%)

Certain precautions must be taken before the two groups can be compared. It is known that the incidence of refractive errors increases with age throughout the school years[5, 8] and the Oregon Study, reported by Gutman[12] shows an increase in the number of failures on the Massa-

chusetts Vision Test with increasing grade. The average age for grades 1-8, the only grades common to both groups, was the same. A difference in the degree and type of refractive error between the sexes has been reported by Hirsch[6] and Young, et al.,[20] however, the proportion of boys and girls in both groups was similar.

A. Number of Failures

Table II, an analysis of the number of children failing the test between the Base and Limestone, yields a chi-square of 5.08. For one degree of freedom, a chi-square of this magnitude may be expected by chance variation alone as often as 2.6 times in a hundred. This probability is low enough to suggest quite strongly that the two groups were not drawn from a common population and the 36.3% failure of the Limestone children is indicative of a real difference when compared with the 30.6% failure rate of the Base children.

TABLE II.

Comparison of the proportion of failures between Grades 1-8 of the Base and Limestone Children.

	Fail	Pass	Total
Base	301.0 (321.5)	683.0 (662.5)	984
Limestone	204.0 (183.5)	359.0 (104.2)	563
Total	505	1,042	1,547

Chi-square = 5.08, for 1 df P = 0.026

Expected values based on chance and derived from marginal totals are in parentheses.

Tables III(a) and III(b) present the number of failures on each subtest for all grades of the Base and Limestone children respectively.

TABLE III. (a)

Number of failures on each subtest for Base Children.

	SUBTEST NUMBER						
Grade	1	2	3	4	5	6	Total
Sub Pr	19	9	5	2	1	1	37
1-8	191	91	52	53	55	18	460
Total	210	100	57	55	56	19	497

TABLE III. (b)

Number of failures on each subtest for Limestone Children.

	SUBTEST NUMBER						
Grade	1	2	3	4	5	6	Total
1-8	167	25	21	23	21	7	264
9-12	86	5	6	10	8	0	115
Total	253	30	27	33	29	7	379

Table IV (a) shows the number of failures on each item for grades 1-8 of the Base and Limestone children, and tests the assumption that there is no difference in the distribution of subtests failed. The chi-square is 33.78 which would not be expected by chance more than once in a thousand and suggests that the Base and Limestone children failed the test for different reasons.

TABLE IV. (a)

Comparison of the number of failures on each subtest for Grades 1-8 between the Base and Limestone.

	SUBTEST NUMBER						
	1	2	3	4	5	6	Total
Base	191.0	91.0	52.0	53.0	55.0	18.0	460
	(227.5)	(73.6)	(46.4)	(48.3)	(48.3)	(15.9)	
Limestone	167.0	25.0	21.0	23.0	21.0	7.0	264
	(130.5)	(42.4)	(26.6)	(27.7)	(27.7)	(9.1)	
Total	358	116	73	76	76	25	724

Chi-square = 33.78, for 5 df. P = 0.001 would require 20.52

Table IV (b) compares the difference in performance on the muscle balance tests, items 3, 4, 5 and 6. We find that it could be expected by chance as often as 80 or 90 times in a hundred.

TABLE IV. (b)

Comparison of the number of failures on the muscle balance subtests for Grades 1-8 between the Base and Limestone.

	SUBTEST NUMBER				
	3	4	5	6	Total
Base	52.0	53.0	55.0	18.0	178
	(52.0)	(54.1)	(54.1)	(17.8)	
Limestone	21.0	23.0	21.0	7.0	72
	(21.0)	(21.9)	(21.9)	(7.2)	
Total	73	76	76	25	250

Chi-square = 0.73, for 3 df. P lies between 0.80 and 0.90.

From Table IV (c) it is apparent that the Limestone children have more failures on item 1, the visual acuity test and fewer on item 2, the plus lens test. The difference is large and is significant at the 0.001 level.

It appears that the Limestone children fail the acuity test more than any other item and it is this failure which is responsible for their higher total failure rate compared with the Base children.

Not indicated in tabular form, an analysis of the number of failures on item 1 for grades 1-4 compared with grades 5-8 revealed no

TABLE IV. (c)

Comparison of the number of failures on subtests 1 and 2 of Grades 1-8 between the Base and Limestone.

	SUBTEST NUMBER 1	2	Total
Base	191.0 (213.0)	91.0 (69.0)	282
Limestone	167.0 (145.0)	25.0 (47.0)	192
Total	358	116	474

Chi-square = 21.79, for 1 df, P = 0.001 would require 10.83

difference for either the Base or Limestone children. A similar analysis of the number of failures on item 2 for the Base children was significant at the 0.06 level and was proportionately higher in the lower grades. The difference observed may be expected to occure by chance as often as 6 times in a hundred, and may be interpreted as suggestive. It should be noted that these data were obtained from a group including spectacle wearers. If all were checked without spectacles, differences by grade may have been noted.

B. Number of children wearing spectacles:

In Table I, we note that 10.3% of the Base children wear spectacles while 17.2% of the Limestone children in grades 1-8 are spectacle wearers. As expected, grades 9-12 show a much higher number of corrected ametropes, 33.3%.

Table V(a), comparing the number of children in grades 1-8 who wear spectacles in the Base and Limestone schools, yields a chi-square of 14.99, which is significant at the 0.001 level. Clearly, the proportion of Limestone children wearing spectacles is greater than the Base children.

TABLE V. (a)

Comparison of the number of children wearing spectacles in Grades 1-8 between the Base and Limestone.

	Wear Spectacles	Do Not Wear Spectacles	Total
Base	111.0 (136.3)	968.0 (942.7)	1,079
Limestone	97.0 (71.7)	466.0 (491.3)	563
Total	208	1,434	1,642

Chi-square = 14.99, for 1 df, P = 0.001 requires 10.83.

Leverett reports that 12.3% of the children in grades 1-12 wore spectacles. Comparison of the Base rate of 10.3% with this figure reveals no significant difference, while the Limestone value is significantly higher. We may then conclude that the Base is comparable to the population in Danbury, but the Limestone group is higher than the norm established.

In Table V(b) the number of Base children failing the test wearing and not wearing spectacles are compared. Chi-square is 10.71, which is almost large enough to conclude that the observed difference is significant at the 0.001 level. In Table V(c) the same analysis is performed for the Limestone children, resulting in a highly significant difference.

TABLE V. (b)

Comparison of the number of Base children failing the test with and without Spectacles for all Grades.

	Fail	Pass	Total
Wear Spectacles	50.0	61.0	111
	(34.4)	(76.6)	
Do Not Wear Spectacles	285.0	683.0	968
	(300.6)	(667.4)	
Total	335	744	1,079

Chi-square = 10.71, for 1 df. P = 0.001 requires 10.83.

TABLE V. (c)

Comparison of the number of Limestone Children failing the test with and without spectacles for all Grades.

	Fail	Pass	Total
Wear Spectacles	112.0	74.0	186
	(70.0)	(116.0)	
Do Not Wear Spectacles	201.0	443.0	644
	(243.0)	(401.0)	
Total	313	517	830

Chi-square = 50.90, for 1 df. P = 0.001 requires 10.83

In both cases, it is obvious that the difference is the result of the fact that many more children wearing spectacles fail the test than do children without spectacles. Leverett reports similar results in the Danbury study.

Not reported in tabular form, the proportion of children wearing spectacles was greater with increasing grade.

RESULTS OF TEACHER JUDGMENT

Copies of the *Teacher's Guide to Visual Problems with Check List*, published by the American Optometric Association, were distributed in the Base schools. No indoctrination of the teachers was per-

formed and no minimum standards were set. No weight was given to the number of items checked or the relative importance of the symptoms noted.

Of 79 folders returned by the teachers, 42 or 53.1% of the children actually failed the screening test. The proportion of failures on each item by the 42 children so selected by the teachers was not significantly different from the distribution of items failed by the entire group. The children identified by the teachers on the basis of class room symptoms did not have any particular visual problem to differentiate them from the rest of the group.

It is quite possible that some of the children selected by the teacher but passed by the test, do have a visual problem requiring attention. The Massachusetts Vision Test does under-refer, and only complete visual examination could determine the true validity of the teacher's choice.

There was considerable individual variation in the accuracy of the teacher's selection. The reliability of the method might be improved if instruction and relative weights were assigned.

VALIDITY OF REFERRALS

A. Reports by the doctors:

An estimation of the validity of referrals was obtained by critical examination of the forms returned by the doctors who ultimately examined the referred children. Only 115 forms were returned for students in the Base schools. Of these, 12 children, 10.2% were incorrectly referred; the examining doctor did not consider the items failed accurate reflections of the child's visual performance. In an additional 7 cases, 6.0%, in which the children failed item 2, the plus test, the doctors granted the presence of moderate hyperopia, of 0.50 to 1.00 diopters, but questioned the need for referral. Therefore, at least 98 of the 117 cases returned, or 83.8% were valid referrals, and accurately reflected the existence of a visual problem requiring professional attention.

Table VI(a) compares the number of incorrect referrals on each subtest as determined by the doctor's reports with the number expected from the proportion of failures on each item. To avoid the use of small expected frequencies, items 4, 5 and 6 were grouped and chi-square computed for four cells. The difference between the observed and expected frequencies is significant at the 0.001 level, and is the result of the unduly high number of erroneous failures on item 3, the vertical phoria tests, and the high reliability of item 1, the acuity test.

The comparison is repeated in Table VI(b) which includes the 7 doubtful failures on the plus lens test, and yields the same conclusions.

TABLE VI. (a)

Number of incorrect failures on each item as judged by the doctors, compared with expected values computed from total failures on each item.

	Subtest Number						
	1	2	3	4	5	6	Total
Observed	4.0	1.0	16.0	4.0	4.0	1.0	30
Expected	12.7	6.0	3.5	3.3	3.4	1.1	30

Chi-square = 55.01, for 3 df*, P = 0.001 requires 16.27.

TABLE VI. (b)

Number of incorrect *and questionable* failures on each item compared as in Table VI (a).

	Subtest Number						
	1	2	3	4	5	6	Total
Observed	4.0	*8.0*	16.0	4.0	4.0	1.0	37
Expected	15.6	7.4	4.3	4.1	4.2	1.4	37

Chi-square = 39.86, for 4 df**, P = 0.001 requires 18.47.

*Cells 4, 5 and 6 combined.
**Cells 5 and 6 combined.

B. Incorrect failure on the first test:

The sparsity of data on incorrect referrals returned by the doctors prompted an estimation of reliability based on performance on the first test and the retest. An item failed on the first test but subsequently passed on the retest may be considered as an incorrect referral.

Unfortunately, the raw data obtained from the number of items failed on the first test cannot be directly interpreted. The testing procedure on the first test eliminated any further examination after the first failure. This sequential failure will result in a bias toward a higher number of initial failures simply because the children were not given an opportunity to perform on the later tests. This objection, although realized by the author in each case, is not overcome by either Leverett or Gutman,[12] and their evaluation of the distribution of items failed is necessarily biased toward the first few items, i.e., the visual acuity and plus lens tests.

In the present study, an estimation of the true proportion of failures on the first and second items was obtained by determining the proportion of subtests 1 and 2 which were not associated with failures on the remaining items of the retest. It was found that on the retest, 139/210 or 66.3% of the failures on item 1 were not followed by failures on any subsequent item and 84/100 or 84% of failures on item 2 after passing item 1, were not followed by failures on other tests. The raw data for the failures on items 1 and 2 of the first test were adjusted accordingly, resulting in elimination of some scores on the assumption that they may have been followed by failures on other items which could not have been reported.

The data, so adjusted, are presented in Table VII in which the observed values are compared with values expected from the proportion

of final failures on each item. The two distributions are significantly different due to the excessively high number of failures on item 2, the plus lens test.

TABLE VII.

Observed number of failures on each item for Base Children who failed the first test but subsequently passed the retest, compared with expected values computed from total failures on each item.

	Subtest Number						
	1	2	3	4	5	6	Total
Observed	29.0*	50.0*	21.0	6.0	20.0	5.0	131
Expected	55.4	26.3	15.0	14.5	14.8	5.0	131

Chi-square = 43.15, for 5 df, P = 0.001 requires 20.52.

*This figure adjusted as explained in the text.

Previous studies and theoretical analysis suggest that more erroneous failures on the plus lens test might be expected in the lower grades due to the higher incidence of hyperopia in younger children.[5, 8] Contrary to these expectations, the number of erroneous failures on each subtest by grade for the Base children yielded no difference in the validity of the plus lens test. The only item evidencing a grade difference was item 5, the near lateral phoria, which showed that more children in the higher grades tend to fail erroneously. It was significant at the 0.05 level, and is only suggestive.

Not reported in tabular form, similar analysis for Limestone revealed a significant peak in the number of erroneous failures on the vertical phoria test, comparable to the doctor's reports for the Base children. There were too few failures on the plus lens test for the masking effect of Table VII to appear.

DISCUSSION

There can be no question, based on the significantly greater number of children wearing spectacles and the higher number of failures, that the children of the town of Limestone have a greater incidence of refractive errors than the Base children. While children with hypermetropia and hypermetropic astigmatism may fail the acuity test and not the plus lens test, they are in the minority. It may be assumed that myopic components are responsible for the observed distribution of items failed.

Essentially the same instruction was given to the test administrators and several parents administered the test in both schools. There is no reason to assume that a different testing or scoring procedure would account for the difference in failure rates. There is also no evidence that the Limestone children have been provided with better visual care than the Base children. In view of the availability of Air Force examination and economic capabilities, the Base children might be expected

to have better visual care, and the higher proportion of spectacle wearers in Limestone is probably indicative of more ametropia.

It might be argued that the children of Air Force personnel have good eyes because they were sired by pilots. This assumption is invalid since less than 10% of the Base personnel are on flying status, and approximately 20% of the flying personnel have refractive errors. In any event, the comparison with Leverett's data showed that the Base is comparable to the number of corrected ametropes in Danbury while Limestone is higher than this average.

To some extent, the results reported for Limestone children grades 1-8 are contaminated by some 75 Air Force children attending school in Limestone. The effect of this contamination would be to reduce any existing differences between the two groups, or to make any residual difference more meaningful.

Nadell and Hirsch[13] report that refractive errors seem to be more prevalent in the case of children whose grandparents came from the same geographical location, while Wixson[18] states that the refractive state of the children is related to that of the parents, and has more of the characteristics of a recessive rather than a dominant hereditary trait.

The people of the town of Limestone have their basic origin in western France. They arrived in the St. John River Valley about 1757 and settled in Aroostook County where they remained in almost complete isolation until 1820. A recently published historical report[9] mentions: ". . . as a people, they have been slow to merge with the Yankee . . . he clings to his own kind, never straying far from his community." A check of the town records of Limestone reveals that from 1892 to 1943, almost all of the marriages occurred between people who were born in Aroostook County or its immediate surrounds. The trend lessens during the war years, due perhaps to the location of two Air Force Bases in the area and the general increase in travel.

On the basis of the historical report, the town records and personal interviews, it appears that the people of Limestone, Maine, fulfill the requirements of homogeneous birthplace of parents and grandparents stated by Nadell and Hirsch. The high incidence of refractive errors in the children of these marriages may be due in part to the appearance of a recessive hereditary tendency as a result of the unavoidable concentration of genetic factors.

The high number of children failing the test who wear spectacles as opposed to the much lower failure rate for the other children suggests that the prescription of spectacles is erroneously interpreted by parents, teachers and doctors to mean that the child requires no further visual attention for a few years. It appears that children who wear spectacles

have more frequent changes in their visual capabilities than children who have never worn spectacles. This is also suggested by the work of Hirsch,[5] who points out that the greatest change in refractive error with increasing age occurs among children with low to moderate myopia. This group is likely to wear spectacles, and thus Hirsch's study implies that children wearing spectacles are more likely to show appreciable changes than children who do not. Hofstetter[8] also presents data confirming this hypothesis.

The lesson to be gained from the present study and the work reported by Hirsch and by Hofstetter is that any child who wears spectacles should be considered as a "first offender" in any return or re-evaluation scheme. They are more likely to show rapid, undetected changes than any other group, and their recheck interval should be reduced accordingly. Spectacle wearers should be referred in the same manner as any other child, rather than by a letter to the doctor as suggested by Leverett.[11]

The value of the teacher's identification of children with visual problems is revealed in the St. Louis study conducted by Crane, Scobee, Foote and Green.[3] They indicate that the sole use of the 20/20 standard on the Snellen chart was no more successful in referral than the judgment of a trained teacher. Ryan feels that those states relying only on the Snellen chart for screening of their children could dispense with their equipment and would do just as well to "just ask the teacher." A later study revealed that the percentage of correct referrals increases if the Massachusetts Vision Test is supplemented by teacher judgment.[4]

A continuing school vision program might include rigid screening by the Massachusetts Vision Test every fall, supplemented by a teacher evaluation in the spring term. The teacher's referral may be considered as suggestive or corroborative to the school authorities and parents. In view of the poor public opinion resulting from over-referrals, it is doubtful if a definite referral should be made if the child has passed the screening and has no other suggestive findings.

The overall validity of the final referrals was good, and is in agreement with the results by Leverett and Ryan. The detailed reports of the doctors indicate that many of the referrals based on the plus lens test correctly identify hypermetropia, but were not clinically warranted. The unreliability of the plus lens test is also reflected in the high erroneous failure rate on the first test when compared with the final retest.

Improvement might be obtained if the partial failure score, which is given if the child reads the 20/30 line with both eyes through the

plus lens, is eliminated. It is possible to read the 20/30 line with a true or artificial myopia of about 0.75 diopters.[1] A patient with a hypermetropic error of 0.75 diopters would have a residual artificial myopia of 0.75 diopters through a +1.50 diopter lens, and may be able to read the 20/30 line, and be referred on this basis.

The +1.50 diopter lens was suggested by Sloan[17] as a tentative value, but prior to the report of the New England Ophthalmological Society,[2] no commercial substitute was available. In compliance with this report, the American Optical Company[14] and the Welch-Allyn Company[16] have issued the test in revised form, which includes a +1.75 and +2.25 diopter lens, and the addition of a 20/40 line to the 20/30 and 20/20 lines previously available.

If the partial failure score is eliminated, and 20/20 acuity through the lens retained as the sole criterion for referral on this item, the +2.25 diopter lens is too strong. The +1.75 diopters lens would probably refer most hypermetropes of 1.25 diopters and above, and pass those with 0.75 diopters and below. The dividing line of about 1.00 diopters of hypermetropia is probably at the clinically significant level for school children. The lack of an observed grade difference in erroneous failures suggests that it is not necessary to introduce the added complication of two lenses for different classes; the +1.75 diopter lens may be used for all grades.

In the opinion of the doctors, the vertical phoria was the most frequent cause of an unwarranted referral. Their reports indicate that the error was not due to the presence of a real but subclinical vertical phoria, but rather to the absence of any appreciable vertical deviation whatever.

It is difficult to explain why the vertical phoria test should be the prime offender in the final referrals to the doctors and the plus lens test for the erroneous failures on the first test. The difference may be due to the variable nature of acuity through a plus lens. A number of children may be just at the borderline of failure; a second test, together with practice effects, may be sufficient to permit passing performance. Whatever the reason for erroneous failure on the vertical phoria test, it is apparently not a borderline phenomenon. The same erroneous factor is present on test and retest, but not in the doctor's office.

Yasuma and Green[19] recommend that all phoria tests be eliminated for children up to and including the second grade. In the present study, the lateral phorias were not responsible for an excessively high number of over-referrals, and there was no grade difference in the unreliability of the vertical phoria test. In addition, quite a few vertical tropias were detected in which the only item failed was the vertical phoria test.

Ryan states that: "Good vision screening should aim at overlooking not even one person . . . even though such an objective may necessitate a considerable number of over-referrals." It is felt that the vertical phoria test should be retained for all grades in keeping with the philosophy expressed by Ryan.

The high reliability of the acuity test suggests that the recommendation of the New England Ophthalmological Society concerning the use of the 20/40 line for grades four and below and the 20/30 line for higher grades, is unduly liberal and is also deplored by Ryan. Passing a child with 20/30 to 20/40 acuity may mean that myopia of from 0.75 to 1.25 diopters is overlooked.[1] Professional judgment may or may not indicate prescription of spectacles, but surely the parents and the doctor should be aware of the condition.

The cover test was responsible for the identification of only three cases of strabismus not detected by any of the other subtests, and its inclusion as a supplementary test may be questioned.

SUMMARY AND CONCLUSIONS

1. The Massachusetts Vision Test was applied to 1,909 children composed of separate groups of Air Force and civilian children. The civilian children were found to include a greater number of spectacle wearers and to have a higher failure rate on the test. Reasons for the differences are discussed and the genetic homogeneity of the civilian community identified as a probable factor.

2. Children wearing spectacles were found to have a significantly higher failure rate on the test than other children. This difference was discussed in the light of prior studies, and was considered as an indication for more frequent re-examination of this group.

3. The inclusion of the teacher's judgment in the Massachusetts Vision Test program was suggested.

4. The overall validity of referrals was about 85% correct. The primary reason for over-referral were found to be the plus lens test and the vertical phoria test. It was suggested that the vertical phoria test be maintained for all grades, but that the partial failure score be eliminated, and the +1.75 diopter lens be used for all grades in the plus lens test.

5. The continued use of a high standard visual acuity test was stressed.

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LOCATING THE CENTER OF VISUAL DIRECTION BY A BINOCULAR DIPLOPIA METHOD*

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This paper is the second of a series of reports concerned with the analysis of visual projection patterns of normal binocular subjects, one-eyed subjects and normal and anomalous correspondence squinters. The first paper[1] confined itself to a discussion of visual direction without regard to the center from which these visual directions proceed; in this report, one approach toward locating the "center of projection" in binocular subjects will be described.

Objective space can be measured quite adequately; however, subjective or visual space is not the space in which the observer manipulates physical objects. Hence, visual space must be measured by having the individual perform in objective space while using only subjective clues. For example, as in the experiment to be described, we can ask him to show us with his hands where a particular visible object is located while his hands are kept from his view by suitable screening devices. If he is unable to see his hands and the object simultaneously, it is not possible for him to correct for a subjective error in direction since he is not aware that an error is being made.

Investigations of visual space using the hands as indicators introduce the variable of hand and eye co-ordination and, in order for these investigations to be valid, proper integration of the two senses must be present. In the parts of the present study where the hands have been used as described above we must then define our results with these facts in mind, i.e., either the direction of visual projection must be assumed to be the direction indicated by the hand, or a method must be found whereby the error introduced by using the hands can be computed from the data. Further, since primary consideration has been given to the localization of diplopic images, it must be assumed that eye-hand coordination is as good using one eye as the other.

If one places his right index finger in line with his right eye and a distant object and his left index finger in line with his left eye and

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the same distant object, he will note that, when he fixates the far object binocularly, the two fingers fuse and the fused image appears to be situated in line with the bridge of his nose and the distant object.

The results of this and similar experiments have led Hering, Helmholtz, Tscherning and others to speak of the "cyclopean eye" or "binoculus" and to place it anatomically at about the root of the nose or the midpoint of the line joining the entrance pupils of the two eyes in binocular subjects. These authors claim, however, that a strong dominance or habitual use of one eye, as in microscopy, may lead to a movement toward one eye of this center of visual directions.

Roelofs and de Favauge-Bruyel[2] conducted a study of the location of the center of projection using methods which depended upon the hands for localizing objects. They used only two binocular subjects and concluded that this center in monocular and binocular vision is located rather far behind the eyes, perhaps in the region of the atlas-axis articulation. If this were so, they said, monocular experiments using targets displaced toward the side of the eye used would produce projection lines crossing the interpupillary line well toward this same eye, but these lines would converge at the atlas-axis articulation in common with lines from points straight ahead in binocular vision. They claimed, therefore, that with monocular vision the apparent shift of the center of projection toward the eye used during the test was an experimental artefact.

Duane[3] stated that in binocular use of the eyes, "projection by the binoculus is performed just as it would be by each eye, if each were transferred to the root of the nose." Convergence, he said, is the function which "transfers the two visual axes to the midline." This would also be true in the case of squinters, even those with anomalous correspondence, so long as both eyes were open and they were "under the domination of the sensations set up by convergence," i.e., Duane believed that in some squinters there would be a single center of projection.

In certain types of squinters, however, Duane claims that the "deviating eye escapes more or less from the influence of . . . convergence" and, even when both eyes are apparently used simultaneously, "acts . . . as though governed . . . by the impressions" of monocular vision. In this case, each eye would project with reference to its own visual axis. He would expect the center of projection to be in or near the eye used, its actual site depending on how much the eye has "escaped" the influence of convergence.

Tschermak[4] believed that a single center of projection existed mid-

way between the eyes at the root of the nose, but in predominant use of one eye—"for instance, in squinters"—it may be shifted toward the dominant eye. "The sensory anomaly (anomalous correspondence) represents not merely two parallel independent egocentric localizations of the two eyes, but a genuine unity—in spite of the unequivalence of the cooperating partners," i.e., a single center of projection exists even in anomalous correspondence. Tschermak was an anomalous correspondence squinter himself.

Brock[5] observes: "We may conclude that one of the essential differences between our form of vision and that of the confirmed squinter is that in normal binocular vision the line of gaze of the right eye and that of the left eye are cortically united to form a single projection axis, whereas in the squinter the line of gaze of each eye forms its own projection axis."

More recently, Francis and Harwood[6] conducted experiments with binocular subjects only and concluded that the center of projection varies laterally with changes in image brightness, moving toward the side of the eye with the brighter image.

Substantial agreement appears to prevail regarding a single center of visual directions at or near the midpoint of the baseline in normal binocular individuals; as to the situation in squinters, marked disagreement seems to argue for further investigation.

The studies which formed the major part of this investigation were those in which images of objects placed on top of a table were localized by the subject using his hands as indicators; his hands were kept hidden from his view under the table. As an initial study of this type, a single near target was placed on the table in the subject's midsagittal plane while he fixated with both eyes a distant target. The points where the diplopic images of the near target were localized were used to determine the location of the center of projection.

APPARATUS AND PROCEDURE

The subject was seated at a comfortable height before a specially constructed table which was 120 cm. high, 115 cm. wide and 90 cm. deep, Figure 1. His forehead and chin were held in position by rests provided (F). He was permitted to see objects placed on top of the table and was required to localize them with his hands which were kept hidden from view under the table, Figure 2.

Along the edge nearest the observer, a translucent sheet of plastic (BB′) which projected 5.5 cm. above the table top served as a screen to prevent the subject from seeing any part of the table top when the pupils of his eyes were positioned six cm. behind the screen and about

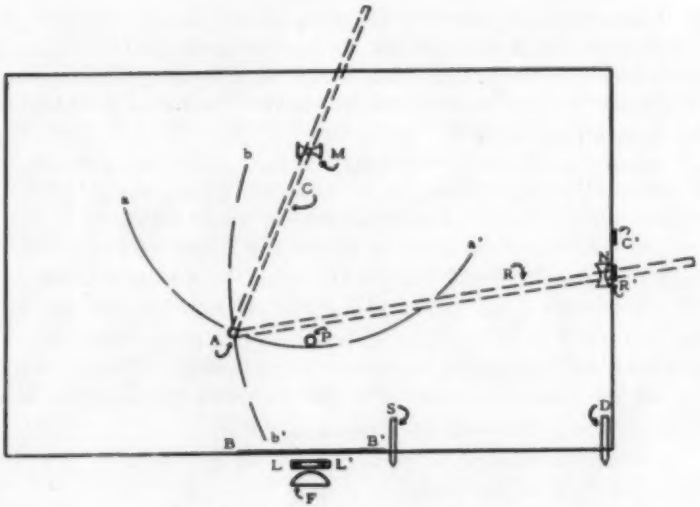

Fig. 1. Top view of the special table used.

one mm. above its top edge. This arrangement prevented him from seeing how or where on the table top the targets were attached.

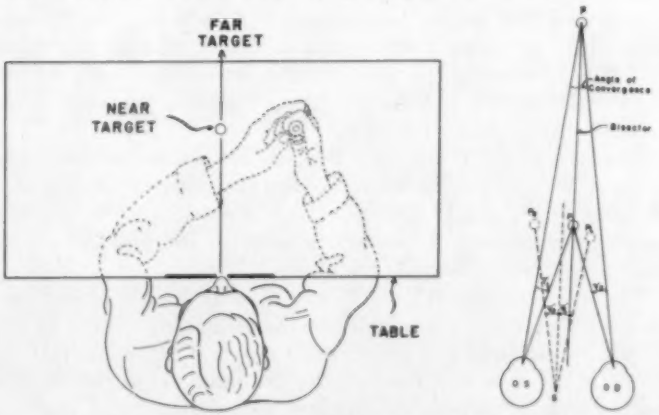

Fig. 2. (Left). Top view of a subject indicating the perceived position of the image of the near target seen by the left eye. The subject's hands and the pointer are under the table.

Fig. 3. (Right). Schematic top view of the binocular diplopia method. The principal line of sight of each eye is directed toward the distant target, $\overline{P}$. Along the midsagittal line, C $\overline{P}$, is the near target, P. P_R and P_L are the images of P seen by the right and left eyes respectively. Between the two eyes is S, the constructed center of projection.

Accurate localization of the right eye in anterior-posterior positioning of the head was provided for by placing the cornea of the right eye in line with the straight edges S and D. The interpupillary line of the subject was kept perpendicular to the line connecting the near target P and the distant target $\overline{P}$.

Lateral positioning of the head was managed by lining up the pupil of each eye and the fixation target with the sighting device, LL′. The pointed vertical rod, L, was suspended just above the pupil of the left eye and was placed one-half the subject's P.D. to the left of the line through the near target P and the far target $\overline{P}$. A vertical pointed rod, L′, was suspended just above the pupil of the right eye and was placed one-half the P.D. to the right of this same line so that this line ($\overline{PP}$) coincided with the midsagittal plane of the subject. During each run the subject periodically checked to see that with the right eye he saw L′ above and in line with the fixation target, $\overline{P}$.

Binocular fixation was maintained on a target, $\overline{P}$, placed 5.7 meters in front of the observer. Figure 3.

A second target, P, was placed in the midsagittal plane of the observer within arm's reach at two different positions. For one position (P_1), the target P was placed so that the angle ψ_R or ψ_L between the line of sight and the target for the right eye or left eye respectively was equal to 7°15′ at the entrance pupil of each eye. In the second position (P_2), the target P was placed so that ψ_R and ψ_L were equal to 4°15′. The distance of the near target from the eyes were so chosen that the angles ψ_R and ψ_L for a given target position remained constant for various interpupillary distances.

The near target P was seen by each eye on the opposite side of the bisector of the angle of convergence and the apparent location of each of the images (P'_R and P'_L) of the target was indicated by the subject by placing the pointer, A, under the table in the position which he believed to be directly beneath the object.

The two horizontal rods R and C were loosely joined to the pointer A. Figure 1. These rods pivoted around the points M and N and could be displaced in a longitudinal direction. Longitudinal movements of rod R were communicated to an indicator on the meter stick R′ via a system of pulleys and longitudinal movements of rod C were likewise communicated to an indicator on the meter stick C′. Both meter sticks (R′ and C′) were placed close together at one side of the table for easy reading. The position of A was recorded as "x cm. from N" and "y cm. from M." The actual position of A with reference to the subject was then plotted on a graph drawn to scale. The coordinate

lines were arcs (aa′ and bb′) centered at M and N. From this graph one could determine the fore and aft displacement of the pointer from the interpupillary line and the lateral displacement from the midsagittal plane. The subject had complete freedom to place the pointer (A) at the distance and direction from his eyes where he felt the image was really located.

Five trials on each image for a total of ten trials constituted one "run." The average of the five trials on each image was taken to plot the apparent position of P'_R or P'_L for each eye. It was assumed that the image $\overline{P}'$ of the fixation point, $\overline{P}$, was projected from the center of projection parallel to the bisector of the angle of convergence.[1] The two points, P'_R and P'_L, were then assumed to be perceived in directions displaced from $S\overline{P}'$ through angles ψ'_R and ψ'_L respectively which are equal to the angles ψ_R and ψ_L between the primary lines of sight and the actual direction of the target, P, at the centers of the entrance pupils. Since bifixation of the target $\overline{P}$ was maintained by the subject, it was not necessary to make any correction for a localization error due to the phoria.

Using these assumed relationships, lines were drawn through the two points P'_R and P'_L so that $\psi'_R = \psi_R$ and $\psi'_L = \psi_L$. The center of projection for this experimental situation is assumed to lie at the point of intersection of these two lines.

RESULTS

Fry[7] has discussed this method as one which is valid for locating the center of projection in binocular invidiuals. As a preliminary investigation, thirteen binocular subjects, ages 21 to 35, were run to determine whether, in a group of normal binocular individuals, this method located a center of projection which agreed with the generally proposed notion that this center was at the midpoint of the line connecting the entrance pupils of the two eyes.

Figure 4 shows the data for the thirteen subjects plotted for center of projection for target P_1. Three subjects were run twice: the open circles were first runs. An arrow joins the same subject's first run to his second run (filled circles). This graph illustrates that when the data for all subjects for target P_1 are grouped together, the average center of projection is found to be located 6.2 cm. in front of the interpupillary line and 0.9 cm. to the left of the midline.

Figure 5 is a plot of the average center of projection when the data for target P_2 are similarly grouped. The average center of projection for P_2 is found to be eight cm. in front of the interpupillary line and 1.2 cm. to the left of the midline. Note that the center of projection located

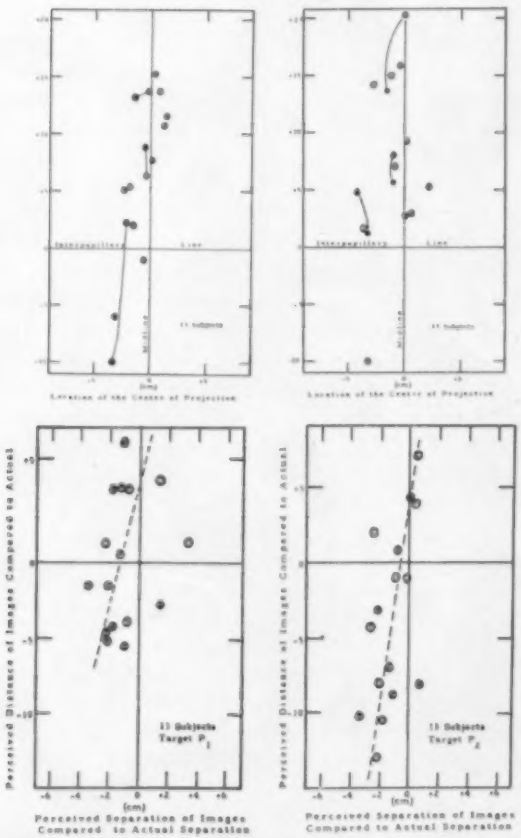

Fig. 4. (Upper left). Center of projection found for 13 subjects when P_1 is used. The open circles represent first "runs"; the filled circles, second "runs." A line connects first and second "runs" for three subjects. Minus numbers on the abscissa represent cm. to the left of the midsagittal line of the subject; plus, to the right of the midsagittal plane. Minus numbers on the ordinate indicate cm. behind the interpupillary line of the subject; plus, cm. in front of the interpupillary line.

Fig. 5. (Upper right). Center of projection found for 13 subjects when P_2 is used. Open circles represent first "runs"; filled circles, second "runs." A line connects the first and second "runs" for three subjects. Plus and minus numbers on the ordinate and abscissa have the same meaning as in Figure 4.

Fig. 6. (Lower left). Perceived separation of diplopic images compared to their actual separation on the table. The sloping dotted line shows the slope of the mathematically derived change in separation of the diplopic images with changes in their perceived distance for P_1. Minus numbers on the abscissa indicate the perceived separation of the diplopic images is less than the mathematical separa-

by this method is generally well in front of the entrance pupil line.

The small differences in the average location of the center of projection for these two target distances probably can be accounted for primarily on the basis of experimental error introduced by the variance in hand-eye coordination of these subjects. Table I shows the raw data for five runs of five trials each for the author. These data, which are representative of data collected from practiced subjects, indicate the magnitude of the errors made in attempting to localize the diplopic images. It should be noted that between each attempt at localizing an image, the hands were removed from the pointer and dropped to the sides of the body. This procedure was followed in an effort to eliminate carry-over effects of postural set.

Attention should be called also to the study by Brown[8] in which six subjects tested during a period of two to nine weeks were required to judge when a horizontal or vertical line was exactly bisected while using only one eye. Trends were found which indicated that apparent size in a given part of the visual field sometimes varies gradually but markedly with respect to time. Since judgments of target location depend essentially on estimation of visual angles in a similar sense to those of Brown's study, it is conceivable that factors acting in the "half-meridional difference" report of his are also factors here.

In Figures 6 and 7, the changes in perceived lateral separation of the diplopic images with changes in the average perceived distance of the images for targets P_1 and P_2 respectively are shown. The sloping dotted line in each graph represents the predicted change in separation of the diplopic images with change in perceived distance based on the assumption that the angle between the two images measured at the midpoint of the interpupillary line should be equal to 14.5° in the case of Figure 6, and 8.5° in the case of Figure 7. Figure 6 for P_1 shows almost no correlation between perceived separation and perceived distance; Figure 7 for P_2, however, shows that some agreement does exist.

On each of these two graphs, minus numbers on the abscissa indicate that the perceived separation of the targets was less than their mathematically predicted separation; on the ordinate, minus indicates that the targets were perceived closer to the subject than their real

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tion; plus indicates the perceived separation is greater than the mathematical separation. On the ordinate, minus numbers indicate that the images were seen closer to the subject than their physical location; plus numbers, that the images were perceived further away than their physical locations.

Fig. 7. (Lower right). Perceived separation of diplopic images compared to their actual separation on the table. The sloping dotted line represents the mathematically derived change in separation of the diplopic images with changes in their perceived distances for P_2. Numbers on the abscissa and ordinate have the same meanings as in Figure 6.

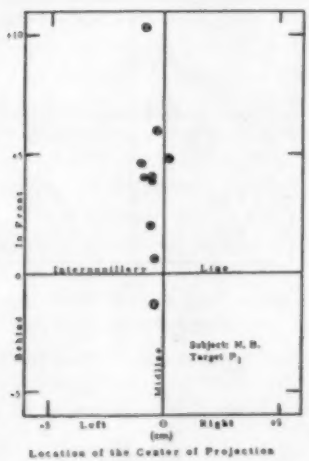
TABLE I

		Trial 1		2		3		4		5		Average	
Date	Image	x	y	x	y	x	y	x	y	x	y	x	y
Dec. 3	Left	1.8	40.6	2.0	40.9	0.7	41.8	2.5	43.1	1.2	43.7	1.6	42.0
	Right	—3.2	39.0	—4.1	40.3	—4.5	41.5	—4.6	42.4	—4.0	42.0	—4.1	41.0
Dec. 3	Left	2.8	38.7	2.9	39.2	3.1	40.8	3.1	41.2	3.5	41.3	3.1	40.2
	Right	—2.0	36.2	—3.2	38.2	—3.8	39.3	—3.9	39.8	—3.7	40.2	—3.3	38.7
Dec. 6	Left	1.0	36.0	1.2	37.5	2.7	37.5	2.5	37.8	2.2	39.1	1.9	37.6
	Right	—3.4	35.8	—4.4	37.9	—3.3	37.5	—3.2	37.7	—4.0	38.0	—3.7	37.4
Dec. 7	Left	1.2	33.9	1.3	35.9	1.0	37.2	1.4	37.8	1.4	38.1	1.3	36.6
	Right	—3.4	34.9	—3.5	36.2	—3.3	37.2	—3.2	37.8	—3.5	38.3	—3.4	36.9
Dec. 7	Left	1.6	38.7	1.6	43.2	2.0	44.0	1.6	45.6	1.9	45.7	1.7	43.4
	Right	—2.9	40.7	—2.4	43.3	—2.6	44.3	—3.8	45.5	—3.2	45.8	—3.0	43.9

Raw data for subject N.B. using binocular fixation of $\overline{P}$ at 5.7 meters in front of the interpupillary line. A near target (P_2) is placed 40.5 cm. in front of the interpupillary line. Both $\overline{P}$ and P_2 are on the midsagittal line. The "left" image is the image of P_2 seen by the left eye: the "right" image is the image of P_2 seen by the right eye.

"X" indicates the distance in cm. to the right or left of the midsagittal line. A minus sign in front of "x" indicates that the image is localized to the left of the midsagittal line: positive values of "x" indicate that the image is localized to the right of the midsagittal line.

"Y" indicates the distance in cm. from the interpupillary line to the localized image: "y" is always positive.



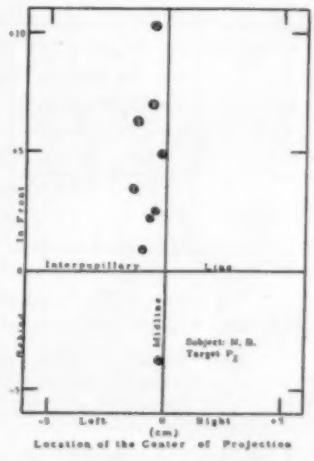


Fig. 8. (Left). The various locations of the center of projection for subject N.B. using P_1 for ten consecutive "runs." Numbers on the abscissa and ordinate have the same meanings as for Figure 4.

Fig. 9. (Right). The various locations of the center of projection for subject N.B. using P_2 for ten consecutive runs.

position in physical space. Hence, these data show rather clearly that the perceived separation of the images is, in general, less than would be mathematically predicted, i.e., most of the points fall to the left of the mathematically derived zero vertical line. In addition, the perceived distance of the target is different from its actual distance.

As a separate experiment, N.B. was used as a subject, and made ten runs over a week's time. The locations of his center of projection for target P_1 are shown in Figure 8. The average of these data shows his center of projection for target P_1 to be located 3.9 cm. in front of the entrance pupil line and 0.5 cm. to the left of the midline. For target P_2 (Figure 9), the center of projection is found 3.7 cm. in front of the entrance pupil line and 0.7 cm. to the left of the midline. Changing the target distance, then, has almost no effect on the location of the center of projection for this subject.

Plots of the perceived locations of the diplopic images of target P_1 and P_2 are shown in Figures 10 and 11 respectively. The two parallel lines on one side of each graph meet the two parallel lines on the opposite side of each graph and form an angle of 14.5° in the case of Figure 10 and 8.5° in Figure 11. The points are grouped closely enough between these lines to suggest that there is some correlation between perceived separation of the targets and their perceived distance from the subject.

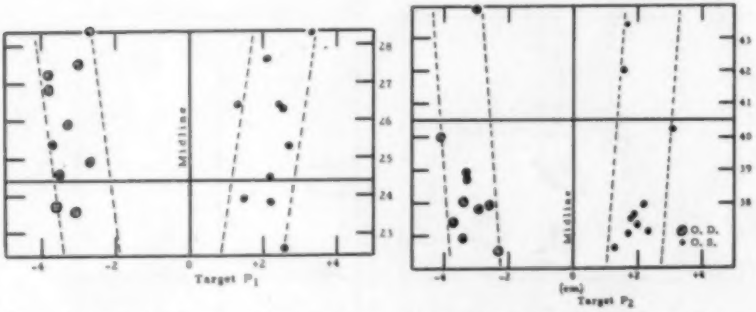


Fig. 10. (Left). The perceived locations of the diplopic images of target P_1 for subject N.B.

Fig. 11. (Right). The perceived location of the diplopic images of P_2 for the subject N.B.

SUMMARY AND CONCLUSIONS

On the basis of the combined data for 13 subjects and the cumulative data for one subject (N.B.), it seems probable that the center of projection in binocular subjects lies near the midsagittal plane when both eyes are used. The apparent fore and aft shift of this center and the discrepancy between the perceived and physical separation of the diplopic images may be due to one or more of the following possibilities:

(1) A true fore and aft change in the location of the center of projection.

(2) A visual error in the perceived angular displacement of each target from the midline.

(3) An error in estimating with the hands the position of a visually perceived image.

Possibilities (1) and (2) cannot be separated easily on an operational basis since fore and aft changes in the location of the center of projection probably would, in themselves, produce visual errors in the perceived angular displacement of objects from the midline or from the line of sight because the subject would have to make an adjustment in angular direction for each change in position of the projection center. Since individuals in their daily life appear to see objects in their correct physical directions, it follows that visual angles are estimated with some precision: it hardly seems reasonable to suppose that moment-to-moment changes in the position of the center of projection actually do occur. It is more probable that possibility (3) forms the basis for these rather erratic variations.

Two factors make this experiment difficult even for practiced observers: (1) blurred, diplopic images separated as widely as were those

reported upon here and viewed for relatively long periods of time are not easily located in a fore and aft direction under any conditions[9, 10] and (2) under ordinary conditions of seeing, use is made of all possible clues to construct a framework and to place ourselves in it; we are not often called upon to make judgments of the nature demanded here. Even if the images are located visually with precision, we are unable to place our hands precisely under them without visual help.

These experiments bring out the fact that when this technique of locating the center of projection is used, a great deal of data must be collected to obtain averages which have significance. This is shown by the spread of points indicating the center of projection for N.B. and also by the unpredictable shifts in center of projection locations for the 13 subjects with changes in target distance. If any two center of projection locations for targets P_1 and P_2 for N.B. were taken consecutively, this same erratic shift in center of projection location would also show up.

It is probable that the center of projection lies on or near the mid-sagittal line, but its position along this line must await further investigation.*

*The work which forms the basis for this report was done in partial fulfillment of the requirements for the degree Doctor of Philosophy in the Graduate School of the Ohio State University. Financial support in connection with this research was provided by the American Optometric Foundation. Mention must be made of the fact that for more than three years, generous contributions of time and knowledge by my advisor Dr. Glenn A. Fry, provided the experimental insight and encouragement which have made this report possible.

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AMERICAN JOURNAL OF OPTOMETRY PUBLISHING ASSOCIATION

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CONFUSED A.M.A. ETHICS

The June 7, 1958, special edition of the JOURNAL OF THE AMERICAN MEDICAL ASSOCIATION is devoted in its entirety to the topic, "Principles of Medical Ethics—Opinions and Reports of the Judicial Council." Optometry can look to many aspects of medical ethics with high regard. Our profession wishes that this high regard could be applied equally to the A.M.A.'s attempts to justify in ethics its stand relative to Optometry.

Ethics is the practical science of the morality of human conduct. Human conduct may either conform or not conform to a people's conception of right. The relationship between behavior and this conception of right determines a people's morality. Recognition of this fundamental concept of ethics is evident throughout the provisions in the ten sections of the Principles of Medical Ethics and throughout most of the opinions and reports pertaining thereto. But, it would seem that the principles of ethics were discarded in the treatment of medicine's rela-

tionship to optometry: it would seem that these principles would have to be discarded in order for the A.M.A. to assume its anti-optometry stand as expressed here.

To clarify fully the conflict between the ethical principles of medicine and the anti-optometry policy contained in the above articles, it is of value to analyze not only the direct references to optometry, but also certain related provisions. First, the Preamble of the A.M.A. Code provides, "These principles are intended to aid physicians individually and collectively in maintaining a high level of ethical conduct. They are not laws but standards by which a physician may determine the propriety of his conduct in his relationship with patients, with colleagues, with members of allied professions, and with the public." "They are not laws" says this Preamble. However, in practice, we know that the anti-optometry provisions have been applied as law governing A.M.A. members. The physician has not been permitted "to determine the propriety of his conduct": rather, he has been coerced into compliance with the implication that his status in his profession is in jeopardy. Are the provisions of the "Principles of Medical Ethics" laws with which A.M.A. members must conform or are they "standards by which a physician may determine the propriety of his conduct in his relationship with patients, with colleagues, with members of allied professions, and with the public"?

The Judicial Council has chosen to interpret section three of the 1957 Code as the basis for the A.M.A.'s anti-optometry policy. This section provides, "A physician should practice a method of healing founded on a scientific basis: and he should not voluntarily associate professionally with anyone who violates this principle." In the reports elaborating on this section, the stand of the A.M.A. is succinctly expressed: "It is unethical for any doctor to teach in any school or college of optometry, or to lecture to any optometric organization, or to contribute scientific material to the optometric literature, or in any way to impart technical knowledge to non-medical practitioners." The Judicial Council goes on to interpret "non-medical practitioners" as meaning specifically optometrists and not "nurses, technicians, or other personnel working with doctors." The discussion in this section also points out, "At no time have optometrists been officially declared sectarian or cult practitioners." The desired A.M.A. conclusion, ethically justified or not, is reached nonetheless as follows: "Thus, the House (of Delegates) has reaffirmed that it is a futile gesture to consult on a professional level with one who does not possess the same knowledge, training, experience, and ideals as the doctor of medicine." Would

it be not just as rational for a proscription of consultation between medical specialists engaged in the practice of different specialties or between specialists and general practitioners? Or, do all physicians have "the same knowledge, training, experience" and thus specialization is such in name only? Is not the optometrist's knowledge more akin to that of the ophthalmologist than is that of the general practitioner? Can it be argued that the optometrist's method of healing is not founded on a "scientific basis"? The Judicial Council of the A.M.A. does not and can not make such a claim; such a claim would apply with equal force to the ophthalmologist in his "method of healing" in the areas of practice which he shares with the optometrist.

In dealing with chiropody in the same section (3), the motive behind the anti-optometry policy would seem to be revealed. Of chiropody, the Council states, "Chiropody is rather a practice ancillary to medical practice *not important enough* (emphasis is the writer's) for a doctor of medicine to attend : . . ." Does the A.M.A. consider that eye care is "too important" for a doctor of medicine to share with the optometrist? It would seem that this is the case. Too important as a desirable area for specialization and for economic gain.

It is the privilege of the A.M.A. to hold whatever stand it desires regarding its members' relationship to optometry. Rightly, it should provoke optometrists, clear thinking physicians and the interested public when the A.M.A. cloaks in ethics an anti-optometry stand which is unsupported in ethical principles and oft-times a hindrance to many individual physicians in adhering to the precept, "The principal objective of the medical profession is to render service to humanity with full respect for the dignity of man." The A.M.A. should divorce its anti-optometric policy from ethics and state it in its true light.

The fact that the A.M.A. persists in trying to make its anti-optometry stand appear to be an ethical consideration is optometry's greatest strength for defense against the many dire actions threatened to bring optometry to extinction. Intelligent people, such as judges, legislators and educators, are not fooled by faulty pronouncements, including those of the A.M.A., and they dislike the implication of any attempt to fool them. By unbiased judgment, optometry's education is sound; its practitioners are rendering a service to humanity; and its professional status is well established. Optometry will prosper and grow in professional stature, irrespective of the A.M.A.'s policy toward it.

LAWRENCE FITCH, O.D.*

*Dean, Pennsylvania State College of Optometry, Philadelphia. Fellow, American Academy of Optometry.

TRANSACTIONS OF THE
AMERICAN ACADEMY OF OPTOMETRY

A department devoted to announcements, reports, appointments, organization data, news, professional problems and ideals, as these relate to the Academy.

AMERICAN ACADEMY OF OPTOMETRY
POST-GRADUATE COURSES
Statler-Hilton Hotel
Boston, Massachusetts
December 10, 11, 12, 1958

GENERAL INFORMATION ON POST-GRADUATE COURSES

Time: All courses are scheduled for the three days immediately preceding the regular annual meeting of the Academy.

Place: All of the courses will be taught in the Statler-Hilton Hotel.

Applicants: Any optometrist may apply for one or more courses. However, Academy Fellows have preference in advance registration until September 24, 1958.

Cancellation: In case of cancellation by applicant the fee will be returned, providing such cancellation is received no later than November 22, 1958.

Cost: The cost per hour of instruction is $2.00 unless otherwise specified.

Enrollment: For most courses the enrollment is not limited. Several specialized courses, however, are limited in enrollment as indicated in the description of courses.

Number of Courses: Fifty-five (55).

Hours of Instruction: One hundred and thirty-four (134).

Applications: All applications should be sent to Dr. D. G. Hummel. The National City Bank Bldg., Cleveland, Ohio.

Deposit: One-half the total fee for each course must accompany the application. The balance must be paid at the commencement of the courses. Courses limited in enrollment must be accompanied by the full fee.

Tickets: Without exception, everyone enrolled in a course must register and pick up the appropriate ticket. Without it, no one can be admitted.

Lecture Rooms: These will be posted at the registration desk. The hotel bulletin board will state the location of the registration desk. Please check your time schedule of courses. The Committee cannot be responsible for conflicts of scheduling.

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R. E. BANNON
H. M. FISHER

COMMITTEE ON ADMINISTRATION
D. G. HUMMEL, Chairman
R. EHRENBERG
M. H. KAUHL

CONDENSED SCHEDULE OF COURSES

Course	Instructor	Subject	Hours	Periods
1	Allen	Subjective Testing Procedures. $4.	2	F-10, F-11
2	Allen	Prism Prescription for Lateral Imbalance. $2.	1	F-2
3	Alton	Basic Principles in Fitting Prosthetic Eyes. $4.	2	T-12, T-1
4	Anapolle	Visual Training and Speed Reading. $8.	4	W-12, W-1 . T-12, T-1
5	Bebber	Accounting and Office Procedures. $4.	2	F-E
6	Bing	Vision Care of Children. $12.	6	T-4, T-5, F-8, F-9, F-12, F-1
7	Bruce	Pathology of the Cornea. $4.	2	F-8, F-9

KEY TO DESIGNATION OF PERIODS

Time	Wednesday	Thursday	Friday
8:00 A.M.	W-8	T-8	F-8
9:00	W-9	T-9	F-9
10:00	W-10	T-10	F-10
11:00	W-11	T-11	F-11
12:00	W-12	T-12	F-12
1:00 P.M.	W-1	T-1	F-1
2:00	W-2	T-2	F-2
3:00	W-3	T-3	F-3
4:00	W-4	T-4	F-4
5:00	W-5	T-5	F-5
8:00	W-E	T-E	F-E

Note: In program of Courses, (E) denotes 8:00 P.M. Evening Course.

SCHEDULE OF COURSES BY HOURS

Hour	Wednesday	Thursday	Friday
8:00 A.M.	---- 8 33 ----	40 36 55 13	7 50 30 6
9:00 A.M.	---- 8 33 ----	40 36 55 13	7 50 30 6
10:00 A.M.	22 38 41 35	22 38 41 23	19 10 16 1
11:00 A.M.	22 38 41 35	22 38 41 23	17 42 16 1
12:00 Noon	---- 37 4 ----	24 3 4 26	21 42 ---- 6
1:00 P.M.	12 37 4 51	24 3 4 26	21 9 52 6
2:00 P.M.	22 38 41 31	22 38 41 46	48 27 14 2
3:00 P.M.	22 38 41 31	22 38 41 46	48 27 14 25
4:00 P.M.	53 45 54 29	47 32 49 6	20 32 49 44
5:00 P.M.	53 45 54 ----	47 32 49 6	18 32 49 44
Evening	34 28 15 11	34 28 15 11	39 5 43

Course	Instructor	Subject	Hours	Periods
8	Cline	Absorptive Lenses, $4.	2	W-8, W-9
9	Connolly & Hathaway	Review and Evaluation of Reminder Systems, $2.	1	F-1
10	Connolly	Signs and Symptoms of Aniseikonia, $2.	1	F-10
11	Copeland	Streak Retinoscopy, $8.	4	W-E, T-E
12	Eschbach	Occupational Vision in the Army, $2.	1	W-1
13	Dick	Practice Management, $4.	2	T-8, T-9
14	Feinberg & Sherman	Optometric Participation in Occupational and Motorists Vision Programs, $4.	2	F-2, F-3
15	Feinbloom, Filderman & Williams	Sub-Normal Vision and Clinic, $16.	4	W-E, T-E
16	Feinbloom	The Physiological Optics of the Partially Blind Eye, $4.	2	F-10, F-11
17	Finkelstein	Corneal Physiology and Contact Lenses, $2.	1	F-11
18	Finkelstein	Clinical Aspects of Contact Lenses, $2.	1	F-5
19	Fry	Evaluation of Quality in Ophthalmic Lenses, $2.	1	F-10
20	Fry	Vision Discomfort—Role of Glare Sources and the Pupil, $2.	1	F-4
21	Giglio	Amblyopia, $4.	2	F-12, F-1
22	Graham, Feinbloom & Mazow	Advanced Course on Corneal Lenses, $32.	8	W-10, W-11, W-2, W-3 T-10, T-11,

Course	Instructor	Subject	Hours	Periods
				T-2, T-3
23	Guth	Lighting Design for Effective Working, $4.	2	T-10, T-11
24	Haffner	Optometric Participation in Community Health and Welfare Programs, $4.	2	T-12, T-1
25	Heath	Color Deficiency in School Children, $2.	1	F-3
26	Heath	Haploscopic Testing of Binocular Vision, $4.	2	T-12, T-1
27	Hebbard	Screening of Visual Fields with Multi-pattern Test Targets, $4.	2	F-2, F-3
28	Hirsch	Ocular Pathology Review Organized by the Section on Pathology, American Academy of Optometry, $8.	4	W-E, T-E
29	Hirsch	Multifocal Lenses for Anisometropic Patients, $2.	1	W-4
30	Hofstetter	Practice Management for Better Inter-Professional Relations, $4.	2	F-8, F-9
31	Kratz	Differential Diagnosis of Myopia, $4.	2	W-2, W-3
32	MacLeod	Recent Developments in Ophthalmic Dispensing, $8.	4	T-4, T-5, F-4, F-5
33	Mark	Clinical Aspects of Ocular Motility, $4.	2	W-8, W-9
34	Mazow	Introduction to Slit Lamp Microscopy, $16.	4	W-E, T-E
35	Morgan	Turville Infinity Balance Test, $4.	2	W-10, W-11
36	Morgan	Unfavorable Prognostic Conditions in Strabismus, $4.	2	T-8, T-9
37	Namias	Adjusting Modern Ophthalmic Frames, $4.	2	W-12, W-1
38	Neill	Modern Contact Lens Fitting, $32.	8	W-10, W-11 W-2, W-3, T-10, T-11, T-2, T-3
39	Peters	Prepaid Optometric Services, $4.	2	F-E
40	Peters	Communications in Eye Safety Programs, $4.	2	T-8, T-9
41	Policoff & Rosenbloom	Subnormal Vision, $32.	8	W-10, W-11, W-2, W-3, T-10, T-11, T-2, T-3
42	Prince	Illustration of Ocular Pathology, $4.	2	F-11, F-12
43	Rayner	Design of Aniseikonic Corrections, $4.	2	F-E
44	Rosenbloom	The Optometrist and His Role in the Reading Program, $4.	2	F-4, F-5
45	Roy	Headaches of Ocular Origin, $4.	2	W-4, W-5
46	Roy	Latent Binocular Stress and Prolonged Monocular Occlusion, $4.	2	T-2, T-3
47	Sager	Practical Aspects of Industrial Optometry, $4.	2	T-4, T-5
48	Sheard	Retinal Images, $4.	2	F-2, F-3
49	Sinn & Simmerman	Management of the Cataract Patient, $8.	4	T-4, T-5, F-4, F-5
50	Sinn	Characteristics of Multifocal Lenses, $4.	2	F-8, F-9
51	Springer	Space Eikonometer Technique of Measuring Aniseikonia, $2.	1	W-1
52	Stewart	House Calls: Examination and Fitting of the Invalid, $2.	1	F-1
53	Vasa	Vision Problems in the Navy, $4.	2	W-4, W-5
54	Wright	Use of Polarization in Ophthalmic Practice, $4.	2	W-4, W-5
55	Wick	Geriatric Optometry, $4.	2	T-8, T-9

A detailed description of all courses will be mailed upon request. See following page.

FOR ADVANCED REGISTRATION

AMERICAN ACADEMY OF OPTOMETRY
BOSTON, DECEMBER 10, 11 AND 12, 1958
STATLER-HILTON HOTEL

Applications should be made to Dr. D. G. Hummel, 1318 National City Bank Bldg., Cleveland 14, Ohio. One-half of the total fee for courses with non-limited attendance and the entire fee for each course with limited attendance must accompany the application. The balance must be paid at the commencement of courses. Without exception, everyone enrolled in courses must register and pick up appropriate tickets for each course. Without them, no one can be admitted. Acceptance of applications will be on a first come first serve basis. When the number allowable in any course is filled, applications will be received on a contingent basis and used in case of cancellation. In case of cancellation the fee will be returned, providing such cancellation is received no later than November 22, 1958.

Advance Order Sheet

Please indicate courses you wish to take.

No. of Course	Instructor	Hours	Total Fee	Date	Time

Name_____

Address_____

City_____ State_____

For Use of the Committee on Administration

Deposit_____ Balance_____

Date Received_____

Notified_____ Date_____ Accepted_____ Contingent_____

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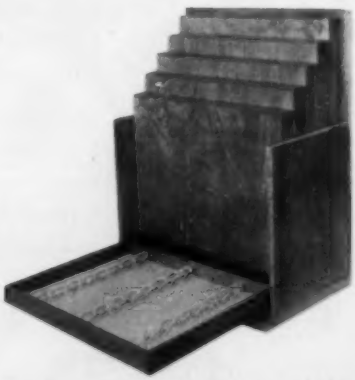

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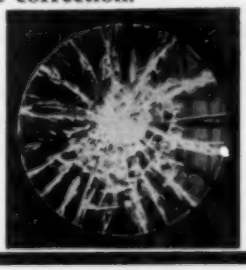

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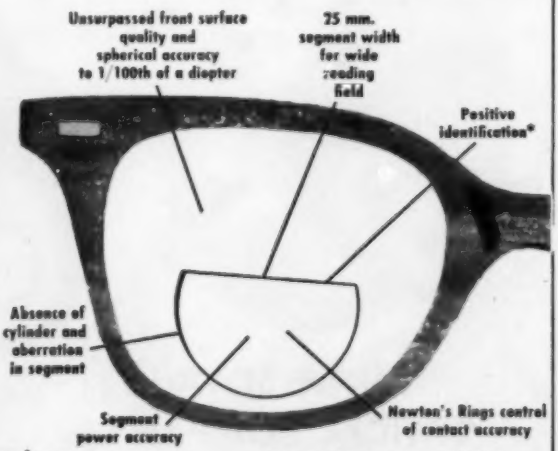
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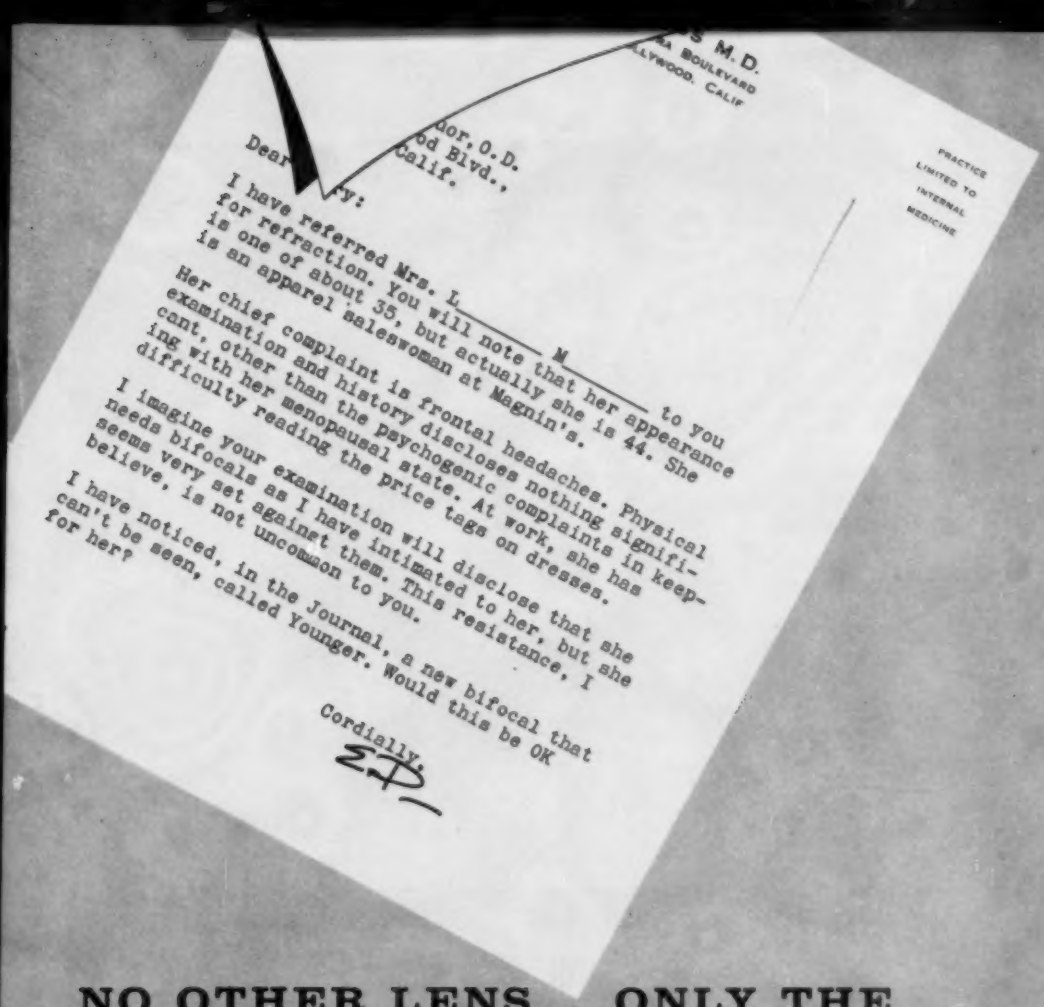
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Dear
I have referred Mrs. L M to you for refraction. You will note that her appearance is one of about 35, but actually she is 44. She is an apparel saleswoman at Magnin's.
Her chief complaint is frontal headaches. Physical examination and history discloses nothing significant, other than the psychogenic complaints in keeping with her menopausal state. At work, she has difficulty reading the price tags on dresses.
I imagine your examination will disclose that she needs bifocals as I have intimated to her, but she seems very set against them. This resistance, I believe, is not uncommon to you.
I have noticed, in the Journal, a new bifocal that can't be seen, called Younger. Would this be OK for her?
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The Younger-22 Seamless Bifocal is particularly indicated for the reluctant presbyope who, on being told they need bifocals, insist instead on a pair of reading glasses. Only Younger Lenses will overcome this resistance in the majority of cases.

The fact that Younger-22 Seamless Bifocals allow the patient clear, comfortable vision for both reading and distance without any confusing or age-revealing dividing line, has a dramatic psychological appeal to those ophthalmic neurotics who resist bifocals for any reason.

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